86751
000006

GeoTrans, inc.
GROUNDWATER SPECIALISTS

46050 Manekin Plaza ▪ Suite 100 ▪ Sterling, Virginia ▪ 20166

703 ▪ 444 ▪ 7000     703 ▪ 444 ▪ 1685 FAX

# CONSTRUCTION AND CALIBRATION OF A THREE-DIMENSIONAL NUMERICAL GROUNDWATER FLOW MODEL

## WINNEBAGO RECLAMATION LANDFILL
## ROCKFORD, ILLINOIS

Prepared for:

July 1995

Winnebago Reclamation Services, Inc.
Rockford, Illinois

GeoTrans, inc.
GROUNDWATER SPECIALISTS
46050 Manekin Plaza
Suite 100
Sterling, VA 20166
703•444•7000 TELEPHONE
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# LETTER OF TRANSMITTAL

DATE 8-14-96 JOB NO 7740-07

RE:

TO MR BERNARD SCHORLE
USEPA REGION V
77 WEST JACKSON BLVD
ATTN: CHICAGO IL 60604-3590

WE ARE SENDING YOU: ☒ Attached ☐ Under separate cover via ______, the following items:

☐ Artwork ☐ Drawings ☐ Copy of letter ☐ Contract ☐ Reprints ☐ Report ☐ Samples ☐ Work Assignment ☐ ______

| COPIES | DATE | NO. | DESCRIPTION |
|---|---|---|---|
| | | | |
| 1 | 7-7-95 | 1 | CONSTRUCTION AND CALIBRATION OF A 3-D NUMERICAL GROUNDWATER FLOW MODEL |

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REMARKS This is the last document to complete the groundwater related reports for the WINNEBAGO RECLAMATION LANDFILL. The other reports were sent under separate cover. These reports were reproduced to reflect the changes made in November 1995, therefore you should not have to do any substitution of pages as described in the Nov 16 1995 letter.

COPY TO ______

GeoTrans, inc.
GROUNDWATER SPECIALISTS

signed Alex Vincent
ALEX VINCENT

FILE: 7740-007

If enclosures are not as noted, kindly notify us at once

# CONSTRUCTION AND CALIBRATION OF A THREE-DIMENSIONAL NUMERICAL GROUNDWATER FLOW MODEL

## WINNEBAGO RECLAMATION LANDFILL

Prepared for:

Winnebago Reclamation Services, Inc.
4920 Forest Hills Road
Loves Park, Illinois 61111

Prepared by:


GeoTrans, Inc.
46050 Manekin Plaza, Suite 100
Sterling, Virginia 20166


NORTH CAROLINA
PROFESSIONAL
SEAL
18547
ENGINEER
PETER A. RICH

GeoTrans Project No. 7735-001

July 7, 1995

GeoTrans, inc.
GROUNDWATER SPECIALISTS

46050 Manekin Plaza ▪ Suite 100 ▪ Sterling, Virginia ▪ 20166

703 ▪ 444 ▪ 7000 FAX: 703 ▪ 444 ▪ 1685

July 7, 1995

Mr. Bernard J. Schorle
United States Environmental Protection Agency
Region V
77 West Jackson Boulevard
Chicago, Illinois 60604-3590

Reference: Reports for the Significant Modification Permit Application
GeoTrans Project No. 7740-000

Dear Mr. Schorle:

GeoTrans, Inc. is pleased to provide you with two copies of the following reports:

1. Report of Hydrogeological Investigations at the Existing Facility
2. Groundwater Impact Assessment Report at the Existing Facility
3. Groundwater Monitoring Plan
4. Groundwater Management Zone Application
5. Groundwater Remedial Alternative Analysis and Preliminary Design (Air Sparging)
6. Construction and Calibration of a Three-Dimensional Numerical Groundwater Flow Model

We look forward to your review of the report.

Should you have any questions, please feel free to call me at (703) 444-7000.

Sincerely,

Daniel K. Burnell

Daniel K. Burnell, P.G.
Senior Hydrogeologist

DKB/eb

Enclosure: as stated

cc: Raj Rajaram, PRC Environmental Management, Inc.
Thomas Hilbert, Winnebago Reclamation Service, Inc.
Daniel R. Feezor, Andrews Environmental Engineering, Inc.

D:\WINNEBAG\LTR-MEM\LTR003.W61

## TABLE OF CONTENTS

**Page**

## LIST OF FIGURES

**Page**

## LIST OF FIGURES
## (Continued)

**Page**

## LIST OF TABLES

Page

# 1 INTRODUCTION

In January 1995, Winnebago Reclamation Services retained GeoTrans, Inc. to construct and calibrate a three-dimensional numerical groundwater flow model to serve as a decision/analysis tool for the existing Winnebago Reclamation Landfill (WRL) and permitted expansion area in Rockford, Illinois. This modeling report describes the development and calibration of the groundwater flow model developed by GeoTrans for the WRL site. The calibrated groundwater flow model was used in March 1995 to estimate the number of recovery wells necessary for capture of impacted groundwater migrating from the landfill (GeoTrans, 1995c). The groundwater flow model was recently refined based on results of new hydrogeologic field investigations performed from late February to May, 1995. After recalibration, groundwater flow modeling and particle tracking were used to demonstrate the appropriateness of the location of upgradient bedrock background monitoring wells (GeoTrans, 1995d).

Since the groundwater flow model synthesizes a large amount of hydrogeologic data while obeying both Darcy's law and conservation of mass, it is a very useful tool for evaluating groundwater flow rates and direction when sufficient data is available. At the WRL site, large amounts of hydrogeologic data have been collected to provide an excellent characterization of the site-specific hydrogeology. Therefore, this model is expected to serve as a very useful tool for understanding groundwater flow conditions at and near the WRL site.

This groundwater flow model report is being submitted to both IEPA and USEPA in order to serve as support for other documents and to assist regulators in understanding the complex hydrogeologic conditions at the WRL site. As part of Illinois ARARs, this report is being submitted as part of the Application for Significant Modification to Permit for an Existing Unit to be compliant with Title 35 Illinois Administrative Code (IAC) 814 Subpart C. In this permit application, the groundwater flow model was used primarily to examine the appropriateness of background monitoring well locations.

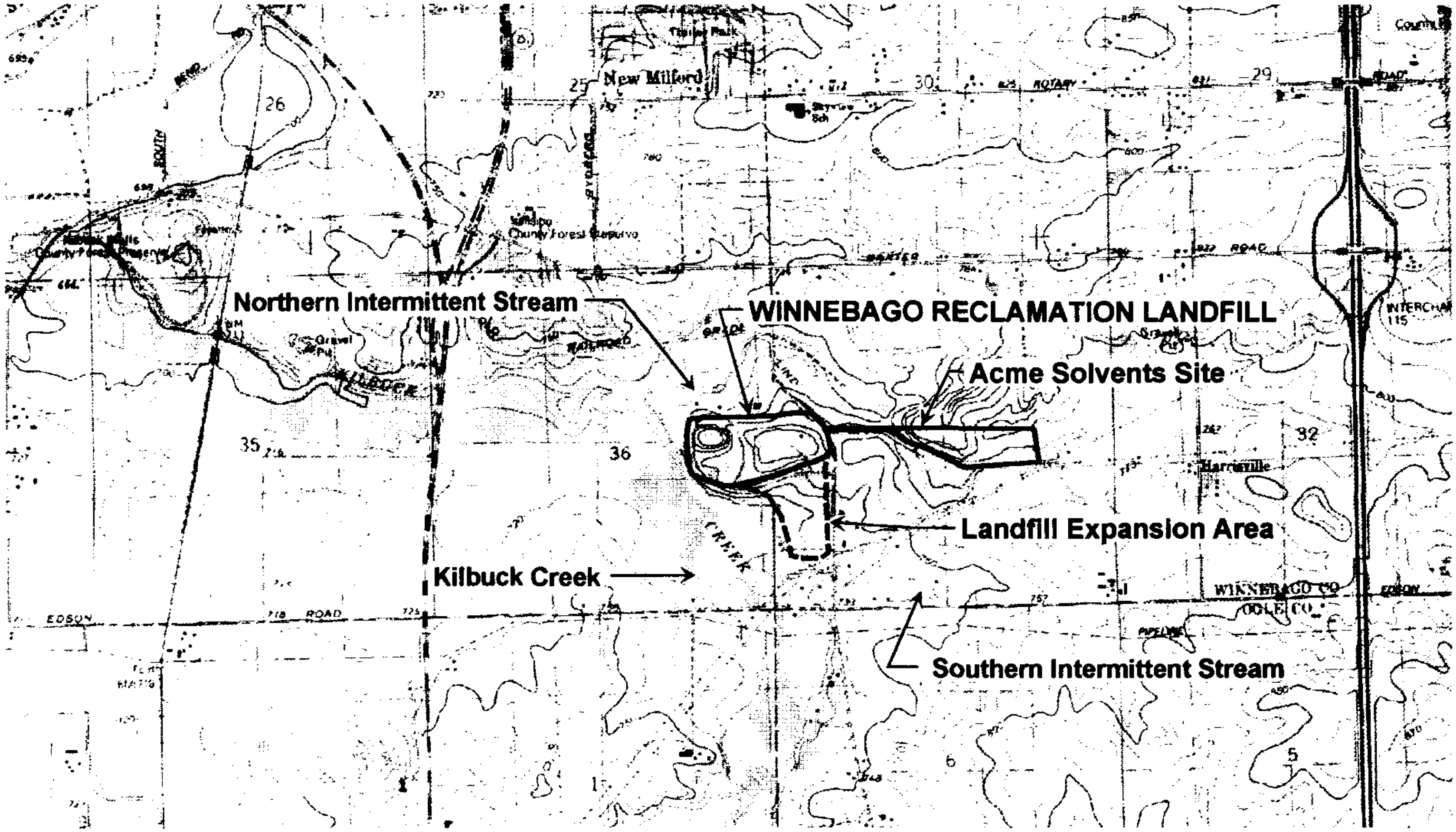
The model was also used as a decision/analysis tool for a design evaluation for a groundwater recovery system at the WRL site. As stated in an earlier submitted engineering design report (GeoTrans, 1995c), the preliminary calibrated groundwater flow model indicated that three recovery wells, each pumping at 150 gpm, are necessary to capture impacted groundwater beneath the landfill. Because of the high capital and O&M costs associated with treating this groundwater which has elevated ammonia levels, GeoTrans (1995c) recommended air sparging and in-situ, natural bioremediation.

The groundwater flow model has been recently refined based on new hydrogeologic data collected from February to March in 1995. This refinement consisted primarily of incorporating newly encountered clay zones west of Kilbuck Creek. However, since no changes were necessary in hydrogeologic conditions in the area of the groundwater recovery, the recalibrated groundwater flow model will provide very similar results regarding the groundwater recovery system design.

## 1.1 SITE LOCATION AND PHYSICAL SETTING

The Winnebago Reclamation Landfill, also known as the Pagel Landfill, is an active municipal solid waste disposal facility located approximately five miles south of Rockford, Illinois (Figure 1-1). This 42.6 acre facility is located on a topographic high bounded by Kilbuck Creek to the west, Lindenwood Road to the east, and intermittent streams to the north and south. Located to the east and upgradient of the WRL site is the Acme Solvents Superfund Site.

The WRL site is located in the Rock River Hill Country of the Till Plains Section of the Central Lowland Physiographic Province of Illinois (Figure 1-2) (Leighton, et al., 1948). The Rock River Hill Country is characterized by subdued rolling hills which rise above alluvial valleys. In the uplands, an extensive drainage system has been developed in which natural lakes, ponds, and marshes are relatively limited in number. Major river valleys in the area are broad with steep walls and alluvial terraces (Hackett, 1960; Leighton et al., 1948).




NOTE:
BASE MAP DEVELOPED FROM ROCKFORD SOUTH, ILLINOIS
7.5 MINUTE USGS TOPOGRAPHIC QUADRANGLE MAP
FIELD CHECKED IN 1992. MAP EDITED IN 1993.


TITLE

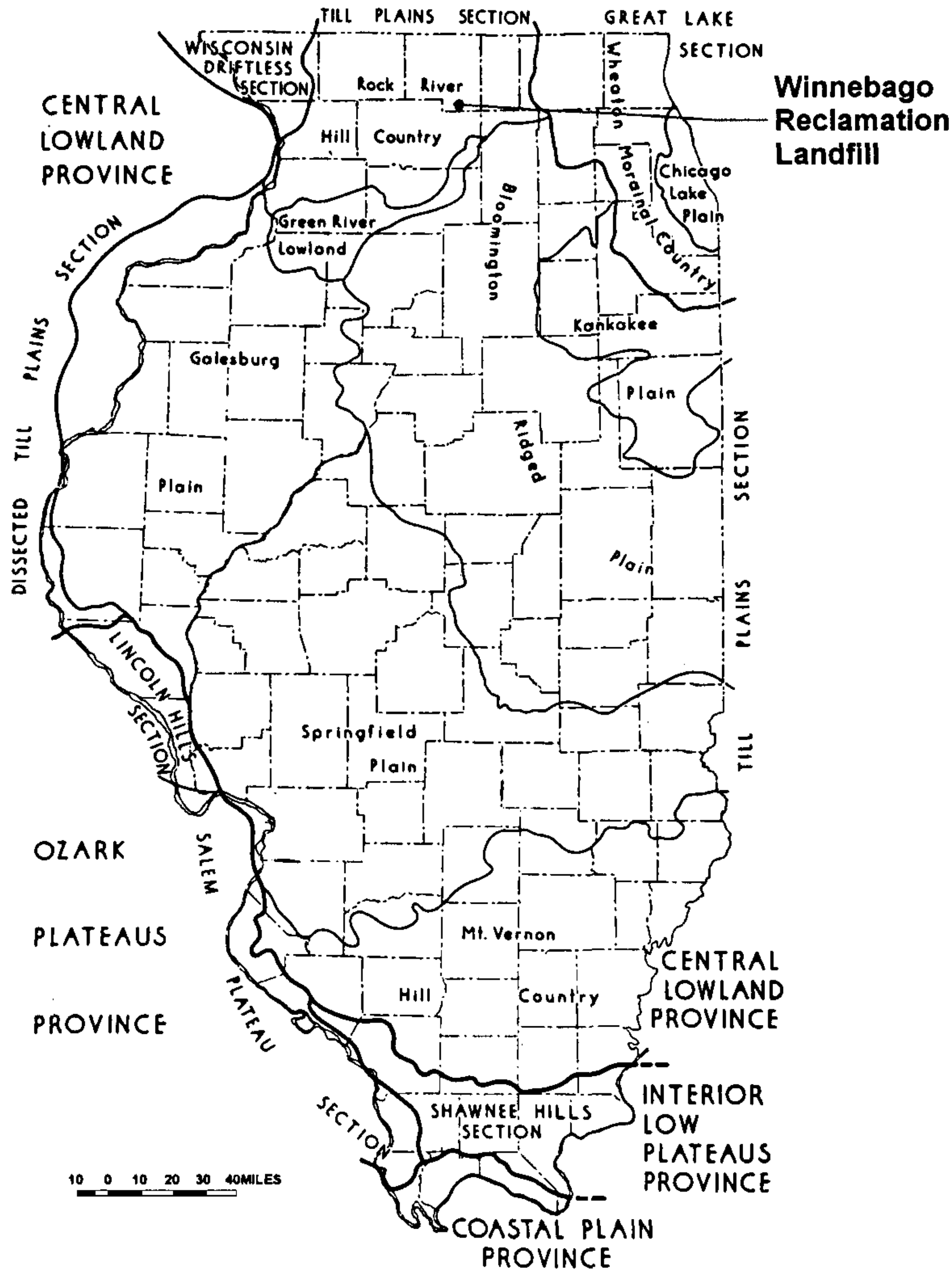
**SITE LOCATION MAP**

LOCATION

Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED | D.B. | FIGURE |
| DRAFTED | P.K. | 1.1 |
| FILE | 7735001A.DS4 | |
| DATE | 6-10-95 | |




ILLINOIS STATE GEOLOGICAL SURVEY
(HORBERG 1957)

| | | | | |
|---|---|---|---|---|
| TITLE | PHYSIOGRAPHIC DIVISIONS OF ILLINOIS | | | |
| LOCATION | Winnebago Reclamation Services, Rockford, IL. | | | |
| GeoTrans, inc. GROUNDWATER SPECIALISTS | CHECKED | D.B. | FIGURE | 1.2 |
| | DRAFTED | P.K. | | |
| | FILE | 7735003A.DS4 | | |
| | DATE | 6-9-95 | | |

Figure 1-3 presents a detailed topographic map of the WRL site with additional site features. The topography of the site consists of a central area of high relief formed by landfilling activities and flat to gently rolling areas away from the landfill. The land surface elevation of the WRL site varies from approximately 706 feet msl at Kilbuck Creek just west of the landfill to 802 feet msl on the top of the landfill. A small leachate collection pond is located on top of the landfill. To the south of the landfill is a small (3.7 acres), low quality wetland. An additional wetland is being constructed to the west of the landfill and is located west of Kilbuck Creek (see Figure 1-3).

The primary hydrogeologic surface water feature in the vicinity of the WRL Site is Kilbuck Creek. Kilbuck Creek, a perennial stream, flows generally to the north, and merges with the Kishwaukee River approximately 2.5 miles to the northwest. The Kishwaukee River merges with the Rock River about 1.5 miles northwest of the confluence of Kilbuck Creek and the Kishwaukee River. Kilbuck Creek receives water from overland flow, discharge from smaller perennial and intermittent streams, and groundwater discharge. The volumetric discharge rate of Kilbuck Creek is highly variable. After major precipitation events, its stage increases significantly and causes bank storage recharge to shallow groundwater. Based on USGS stream gage data in 1988, the volumetric discharge rate of Kilbuck Creek varied from a low of 15 cubic feet per second in September to a high of 188 cubic feet per second in April (USGS, 1988).

The average annual precipitation near the WRL site is 37 inches based on data collected from 1951 to 1980 at the RFD 222 Weather Service Office located approximately 1.5 miles northwest of the WRL site (NOAA, 1982). Precipitation is generally lowest in February and highest in June. As expected, groundwater recharge is generally lowest in the winter during frozen conditions and highest in the spring from snowmelt and greater rainfall.

## 1.2 Study Objectives and Scope

The objective of this modeling study at the WRL is to develop a groundwater flow model for use as a practical decision-making tool. To develop this model, existing hydrogeologic data collected at and near the site and additional regional information found

Figure 1-3. Detailed Site Map.

(This figure can be found in the pocket in the back of this report.)

in the literature were used. The scope of this study includes the development and calibration of a three-dimensional groundwater flow model for an area surrounding the WRL site; future use of the model for predictive simulations will be a part of future modeling investigations at the site.

This groundwater flow modeling report describes the results of the following four major components of the modeling study at the WRL site:

1. Development of a conceptual model of groundwater flow for the WRL based on existing data collected at the site and contained in the literature;

2. Construction of a three-dimensional numerical groundwater flow model;

3. Calibration of the numerical groundwater flow model to measured conditions at the site;

4. Analysis of groundwater flow directions and rates at the site.

# 2 CONCEPTUAL MODEL

A conceptual groundwater flow model succinctly describes the principal components of a groundwater flow system and is developed from regional, local, and site-specific data. The primary components of groundwater flow systems include: 1) areal extent, configuration, and type of aquifers and aquitards; 2) hydraulic properties of aquifers and aquitards; 3) natural groundwater recharge and discharge zones; 4) anthropogenic groundwater sources and sinks; and 5) areal and vertical distribution of groundwater hydraulic head potential. These aquifer system components serve as a framework for the construction of a numerical groundwater flow model.

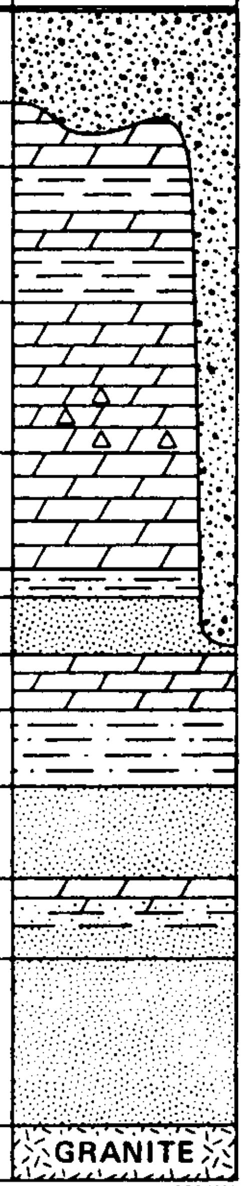
## 2.1 OVERVIEW OF REGIONAL HYDROGEOLOGY

This section of the report presents an overview of the regional hydrogeology of the study area. This discussion emphasizes regional hydrogeologic features that affect groundwater flow in the unconsolidated sediments, and the Galena and Platteville Groups. Additional reports are available that provide a more detailed discussion of the regional hydrogeology of northern Illinois, which includes groundwater flow in the St. Peter Formation (i.e., Visocky et al., 1985; Berg et al., 1984; Hackett 1960; and others).

### 2.1.1 REGIONAL GEOLOGY

The uppermost geologic units of interest in the study area are the Quaternary unconsolidated deposits and the underlying Ordovician dolomites of the Platteville and Galena Groups. Figure 2-1 shows a generalized stratigraphic column for Winnebago County. The Quaternary unconsolidated sediments vary from zero feet in thickness in areas to the east where bedrock outcrops to over 400 feet in thickness in areas to the west where a major bedrock valley is present. Although not present at the study area, the Maquoketa Shale is present in the southeast portions of Winnebago County, and in other isolated portions in the county. In the study area, unconsolidated sediments overlie dolomite bedrock of the Galena

| SYSTEM | GROUP | FORMATION & THICKNESS | GRAPHIC COLUMN |
|---|---|---|---|
| QUATERNARY 0 - 0.7 m.y. B.P. | | 0 – 450 ft | |
| SILUR. 405 - 440 m.y. B.P. | | 50 ft | |
| ORDOVICIAN 440 - 490 m.y. B.P. | Maquoketa | 150 – 200 ft | |
| | Galena | 250 ft | |
| | Platteville | 100 ft | |
| | | Glenwood 5 – 60 ft | |
| | Ancell | St. Peter 200 – 400 ft | |
| CAMBRIAN 500 - 515 m.y. B.P. | | Potosi 50 – 100 ft | |
| | | Franconia 50 – 100 ft | |
| | | Ironton – Galesville 75 – 170 ft | |
| | | Eau Claire 350 – 450 ft | |
| | | Mt. Simon 1000 – 1600 ft | |
| PRECAMBRIAN | | | GRANITE |



ISGS 1981

(HORBERG 1984)

TITLE

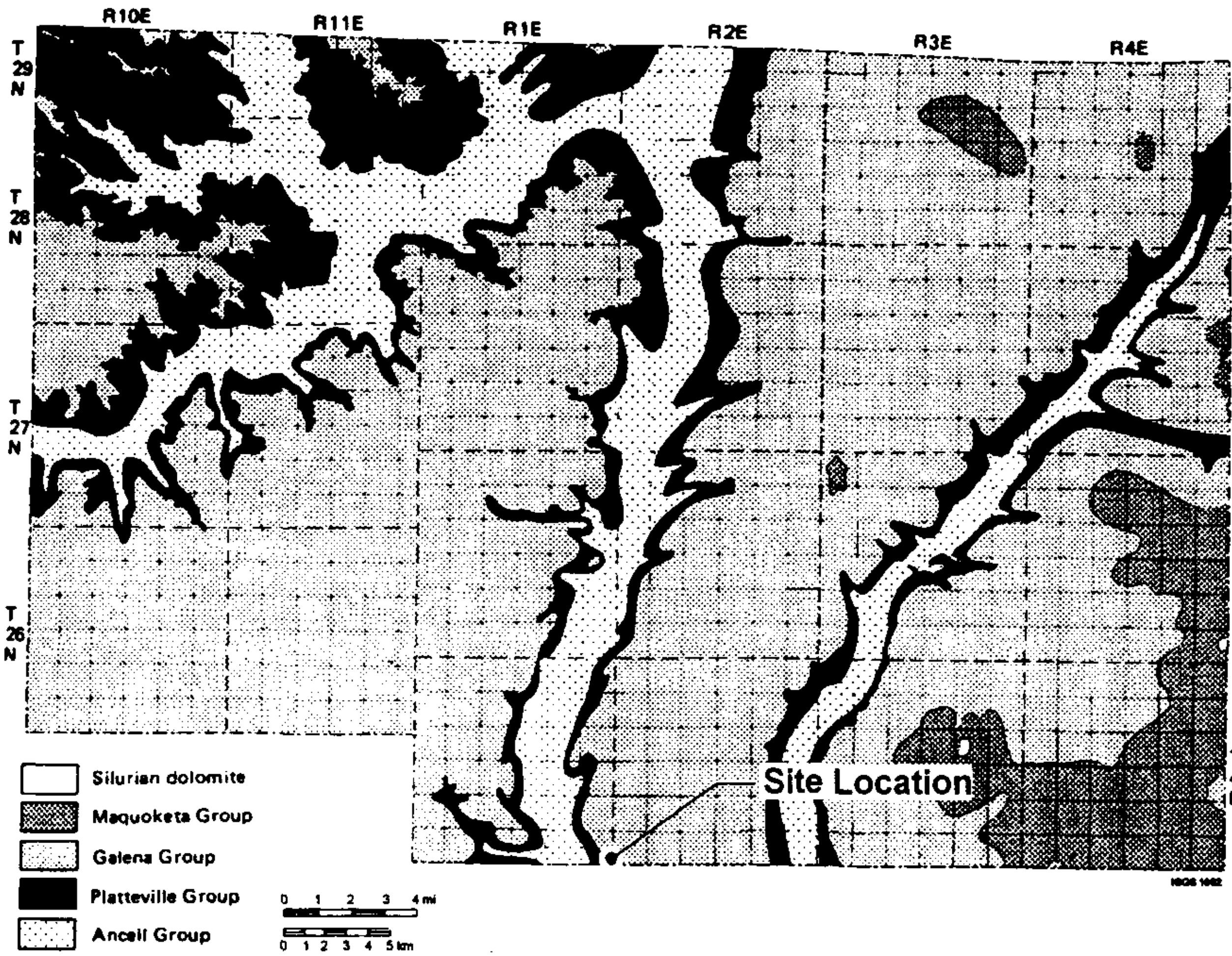
**GENERALIZED STRATIGRAPHIC COLUMN FOR WINNEBAGO COUNTY**

LOCATION

Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED | D.B | FIGURE |
| DRAFTED | P.K. | 2.1 |
| FILE | 7735003A.DS4 | |
| DATE | 6-9-95 | |




(HORBERG 1984)

| | | | | |
|---|---|---|---|---|
| TITLE | AREAL GEOLOGY OF BEDROCK SURFACE | | | |
| LOCATION | Winnebago Reclamation Services, Rockford, IL. | | | |
| GeoTrans, inc. GROUNDWATER SPECIALISTS | CHECKED | D.B. | FIGURE | 2.2 |
| | DRAFTED | P.K. | | |
| | FILE | 7735001A.DS4 | | |
| | DATE | 6-9-95 | | |

Group. Berg et al. (1984) state that the average thickness of the Galena Group is approximately 250 feet in northern Illinois. The Platteville Group underlies the Galena Group. The Platteville Group is approximately 100 feet thick in northern Illinois, and is noted for its continuity over large areas. Below the Galena and Platteville Groups is the Ancell Group, which consists of the Ordovician-age Glenwood and St. Peter Formations. A general description of the lithology of each unit in the study area is provided below.

The St. Peter Formation is a medium- to coarse-grained, well rounded and sorted, poorly cemented, quartz sandstone. In areas where it has not been eroded, the St. Peter Sandstone ranges in thickness from 200 feet to 360 feet with an average thickness in Winnebago County of 265 feet (Hackett, 1960). Because of its friable nature, no recovery was achieved in coring attempts in three borings at the Acme Solvent site. The St. Peter is areally extensive and is widely used as an aquifer in Winnebago County.

The Glenwood Formation overlies the St. Peter Formation. The Glenwood Formation generally consists of interbedded carbonates, sandstone, and shale. The lithology of the Glenwood Formation is highly variable both vertically and laterally. The carbonates are light gray to green and lithographic to finely crystalline. The sandstones within this formation are fine- to coarse-grained with well-rounded quartzose sand. The shales are generally gray-green to blue-green, and occur as thin partings within the sandstones and carbonates. At soil boring STI-DC1, located at the Acme Solvent site, the Glenwood Formation is 36 feet thick and is moderately to little fractured except for the extensive fracturing in its basal beds.

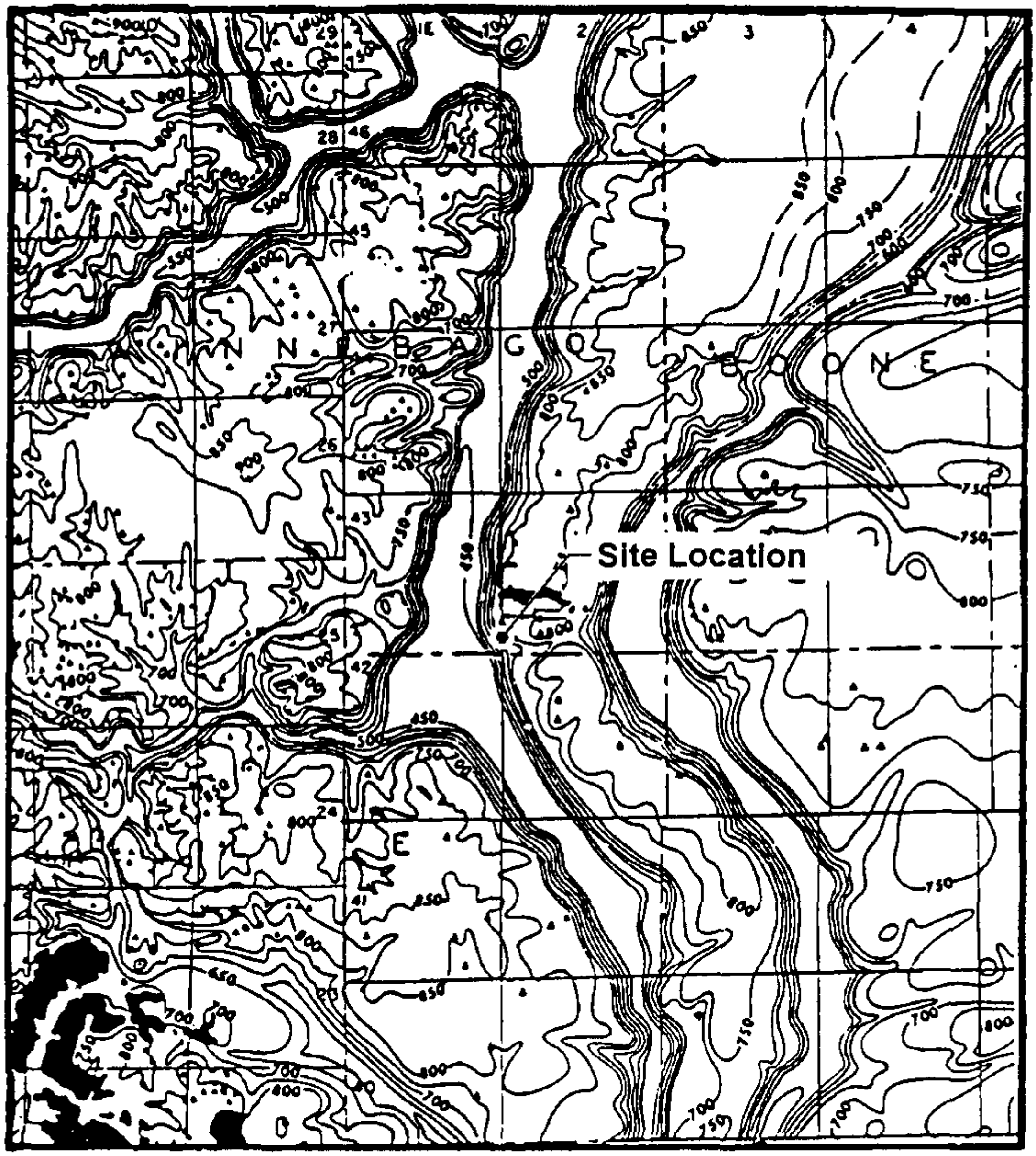
Overlying the Glenwood Formation, the Platteville and Galena Groups have a combined thickness of approximately 350 feet in Winnebago County. These two groups are distinguished primarily through subtle differences in silt and clay content. The Platteville Group consists of limestone formations that are continuous over large distances. The Galena Group is divided into two subgroups: 1) shaley Decorah subgroup at its base; and 2) relatively pure limestone and dolomite Kimmswick subgroup that forms most of the Galena Group. Hydrogeologic studies at the WRL and Acme sites indicate that the upper part of the Kimmswick subgroup is weathered with numerous fracture zones (Staurowsky, 1991; Warzyn, 1991; HLA, 1990).

Figure 2-2 shows the areal geology of the bedrock surface in Winnebago County (Horberg, 1984). This figure shows that the WRL site overlies the Ordovician-age Galena and Platteville Groups. It is also apparent that the WRL site lies on the eastern edge of a major bedrock valley in which the Galena and Platteville Groups have been eroded, exposing the Ancell Group. The Ancell Group is also exposed in another major bedrock valley located approximately five miles east of the study area.

A regional bedrock surface elevation map, which includes the study area, is presented in Figure 2-3. The two bedrock valleys mentioned above are more clearly shown in this figure. In the bedrock valley located west of the site, the elevation of bedrock decreases to approximately 450 feet msl in the central part of the valley. Figure 2-3 also shows that, in the vicinity of the WRL site, bedrock is present at elevations ranging from approximately 650 feet msl to the west and 750 feet msl to the east. Northeast of the site, bedrock elevation increases to approximately 800 feet msl in a local bedrock topographic high area.

Figure 2-4 shows the major regional bedrock valleys in northern Illinois. The two bedrock valleys in the study are the Upper Rock and Troy Bedrock Valleys. These ancient deeply-incised bedrock valleys were filled with unconsolidated sediments during Illinoisan and Wisconsin episodes of glaciation. The Upper Rock Bedrock Valley, which now coincides with the present day Rock River, is located just to the west of the WRL. The Troy Bedrock Valley is located approximately five miles to the east of the WRL.

As stated earlier, unconsolidated sediments overlie the Kimmswick subgroup of the Galena Group in the study area. The unconsolidated sediments consist of primarily glacial drift deposits which include both ice and water-lain materials. The regional thickness of these glacial deposits is shown in Figure 2-5. The poorly-sorted sand and gravel glacial ice-contact deposits of the Wasco Member of the Henry Formation are mapped as present beneath the WRL site and to the east (Figure 2-6). West and north of the site, the sand and gravel outwash deposits of the Mackinaw Member of the Henry Formation are present. In the floodplain of Kilbuck Creek, Cahokia alluvium overlies the Mackinaw Member deposits. To the south of the WRL site, the surficial deposits are mapped as the clays of the Esmond Member of the Glasford Formation (Berg et al., 1984).




(Horberg 1957)

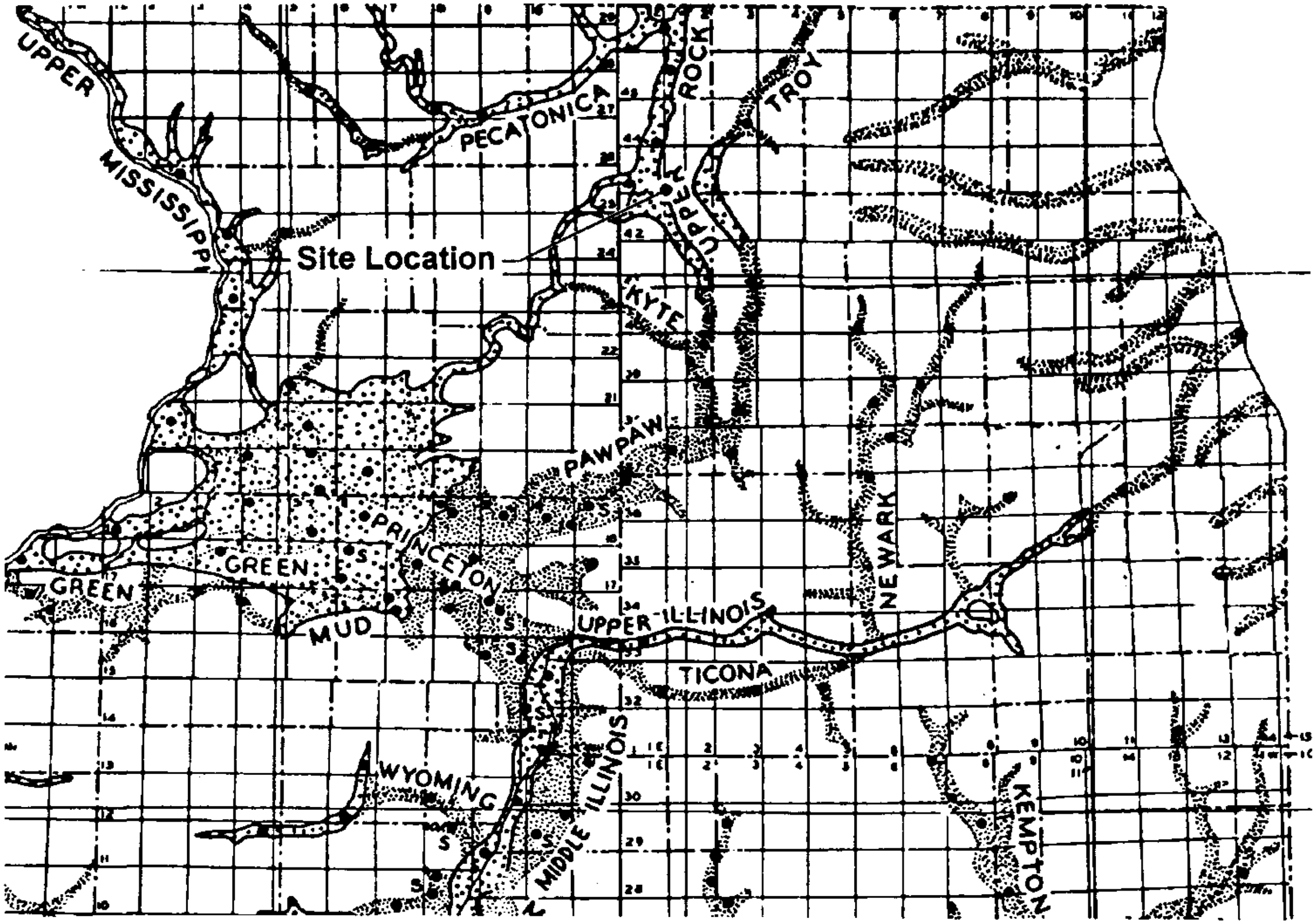
0 5 10 miles
SCALE

NORTH

450 CONTOUR ELEVATION

BEDROCK EXPOSURE

| TITLE | | | | |
|---|---|---|---|---|
| REGIONAL BEDROCK SURFACE | | | | |
| LOCATION: Winnebago Reclamation Services, Rockford, IL. | | | | |
| GeoTrans, inc. GROUNDWATER SPECIALISTS | CHECKED | D.B. | FIGURE | 2.3 |
| | DRAFTED | P.K. | | |
| | FILE | 7735003A.DS4 | | |
| | DATE | 6-9-95 | | |




(HORBERG, 1957)

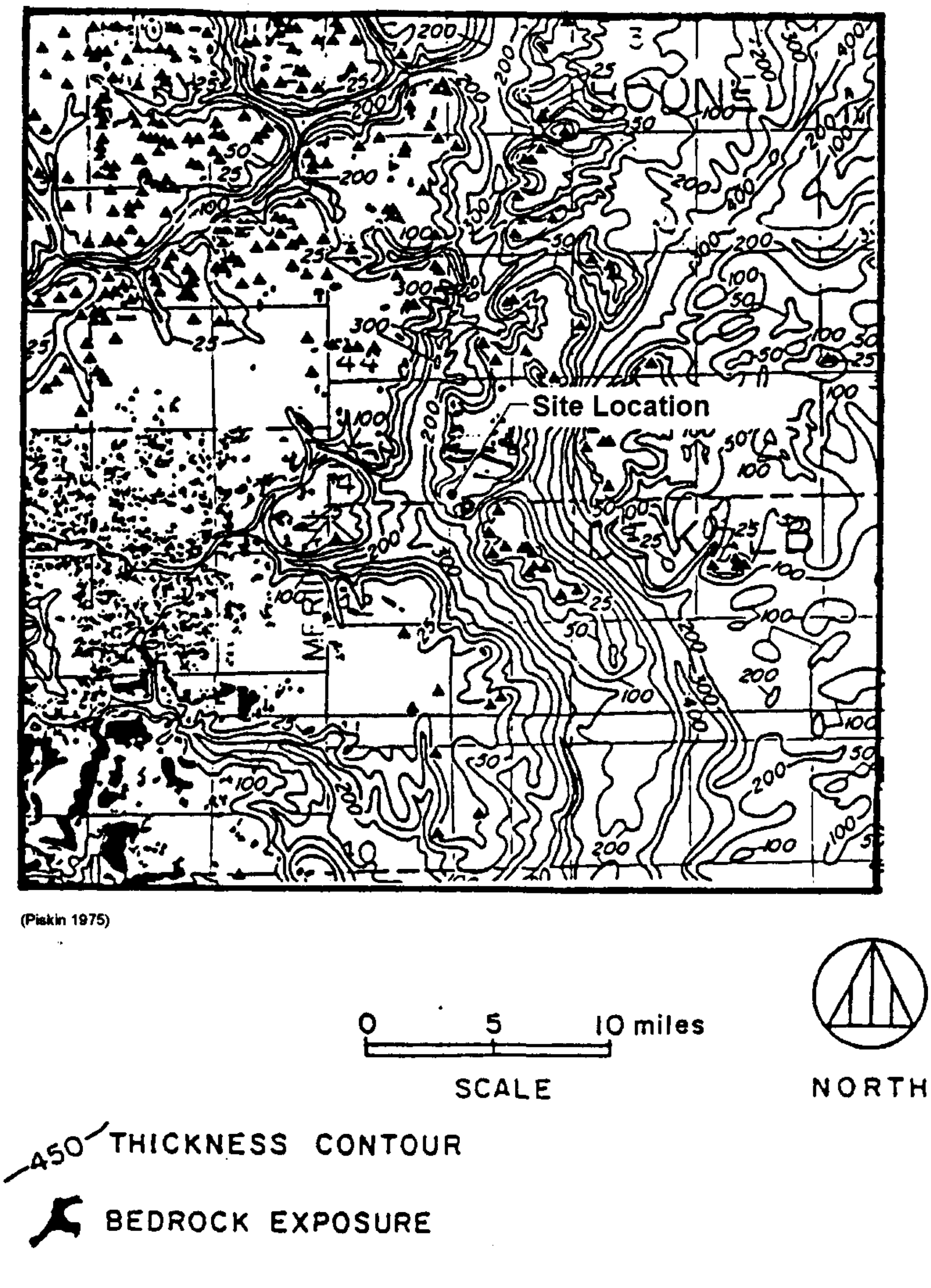
LEGEND

- BEDROCK VALLEYS WHICH COINCIDE IN GENERAL WITH PRESENT VALLEYS AND LOWLANDS
- BURIED BEDROCK VALLEYS
- ● AREAS PRODUCING WATER FROM SAND AND GRAVEL IN BEDROCK VALLEYS
- ○ AREAS WHERE SAND AND GRAVEL DEPOSITS WERE PENETRATED IN BORINGS
- s SANKOTY SAND PENETRATED

SCALE

0 10 20 30 MILES

| TITLE | | | |
|---|---|---|---|
| MAJOR REGIONAL BEDROCK VALLEYS | | | |
| LOCATION: Winnebago Reclamation Services, Rockford, IL. | | | |
| GeoTrans, inc. GROUNDWATER SPECIALISTS | CHECKED | D.B. | FIGURE |
| | DRAFTED | P.K. | 2.4 |
| | FILE | 7735001A.DS4 | |
| | DATE | 4-30-95 | |



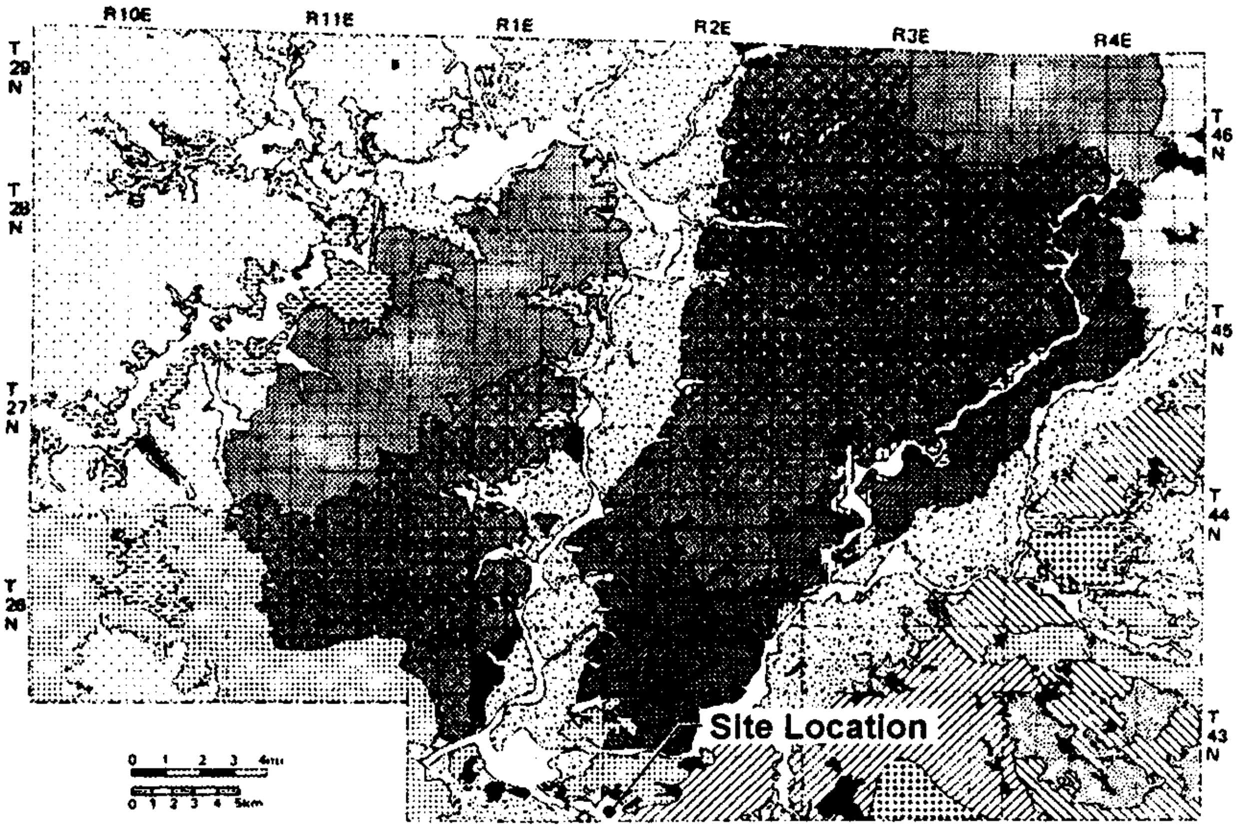

TITLE

**THICKNESS OF GLACIAL DEPOSITS**

LOCATION

Winnebago Reclamation Services, Rockford, IL.

| | | | |
|---|---|---|---|
| GeoTrans, inc. GROUNDWATER SPECIALISTS | CHECKED | D.B. | FIGURE |
| | DRAFTED | P.K. | 2.5 |
| | FILE | 7735003A.DS4 | |
| | DATE | 6-9-95 | |




(BERG et al. 1984)

**FORMATION**
Member

| | | |
|---|---|---|
| CAHOKIA ALLUVIUM | (c) | sand, silt and clay deposited by modern rivers and streams |
| GRAYSLAKE PEAT | (gl) | peat and muck often interbedded with silt and clay |
| **EQUALITY** | | |
| Carmi | (ec) | silt and clay deposited in glacial lakes |
| Dolton | (ed) | medium-to-coarse sand deposted in former glacial lakes |
| **HENRY** | | |
| Mackinaw | (hm) | thick deposits of sand and gravel in major river valleys |
| Wasco | (hw) | near ice deposits of poorly sorted sand and gravel |
| **WINNEBAGO** | | |
| Capron | (wic) | pinkish-brown friable silt loam till |
| Clinton | (wicl) | yellowish-tan, very friable, very sandy till |
| Argyle | (wia) | pinkish- or buff-tan often friable sandy till |
| Nimtz | (win) | gray-brown or buff often compact sandy or sandy loam till |
| **GLASFORD** | | |
| Unnamed outwash | (g-o) | sand and gravel deposit overlying Belvidere Till |
| Belvidere | (gbl) | pinkish or pale brown silty or silt-loam till |
| Esmond | (ge) | grayish-brown silty clay till |
| Oregon | (gor) | pinkish-brown or buff-tan sandy till |
| Creston | (gc) | pinkish-brown silty clay loam till |
| Ogle | (go) | yellowish-brown or buff sandy loam till |

ISGS 1983

TITLE

**REGIONAL MAP OF SURFICIAL DEPOSITS IN BOOME AND WINNEBAGO COUNTIES.**

LOCATION

Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

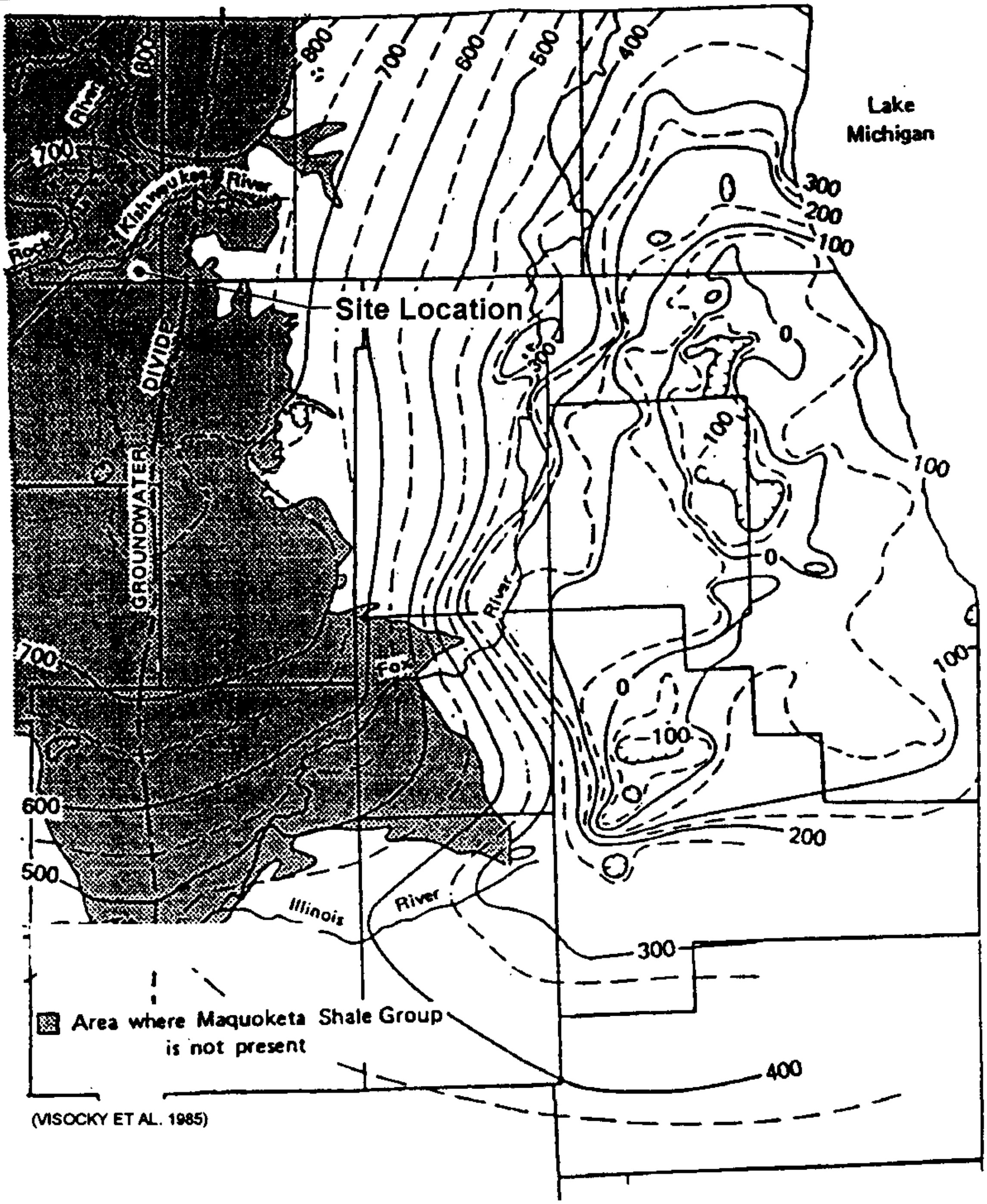
| | | |
|---|---|---|
| CHECKED | D.B. | FIGURE |
| DRAFTED | C.S. | 2.6 |
| FILE | 7735003A.DS4 | |
| DATE | 6-9-95 | |

### 2.1.2 REGIONAL HYDROSTRATIGRAPHY

Based on the details discussed above, these regional stratigraphic units were classified into regional hydrostratigraphic units. This classification is consistent with other hydrogeologic studies in the study area (i.e., Kay, 1991; Staurowsky, 1991; Warzyn, 1991). For example, the poorly sorted sand and gravel deposits of the Wasco Member, sand and gravel outwash deposits of the Mackinaw Member, Cahokia Alluvium, and other transmissive hydraulically connected unconsolidated units in the area are classified as the sand and gravel aquifer. The Galena and Platteville Groups are classified to be the Galena-Platteville dolomite bedrock aquifer. The sand and gravel aquifer and the dolomite bedrock aquifer are hydraulically connected, and form the unconsolidated and upper bedrock aquifer system. Below the unconsolidated and upper bedrock aquifer system is the Glenwood Formation, which forms the basal confining unit for this aquifer system. Below the Glenwood Formation, the St. Peter Sandstone forms part of a separate confined aquifer system.

Although a regional potentiometric surface map is not available for the unconsolidated and upper bedrock aquifer system, Figure 2-7 shows a large-scale regional potentiometric surface map which includes the Galena-Platteville bedrock aquifer. It is apparent that a regional groundwater divide is present approximately three miles west of the study area. To the west of the divide, groundwater flows to the west toward the Rock River with local flow toward the Kishwaukee River. To the east of the divide, groundwater flows to the east toward the large cones of depression caused by pumping in the greater Chicago area.

In areas where the unconsolidated and upper bedrock aquifer system is present, groundwater flow in the unconsolidated and bedrock aquifer system is expected to be generally consistent with the potentiometric surface map shown in Figure 2-7. For example, the groundwater recharge area and divide of the unconsolidated and upper bedrock aquifer system is the bedrock uplands area located approximately three miles west of the study area (Figure 2-3). This is consistent with the regional divide (Figure 2-7). To the east of the




TITLE

**REGIONAL POTENTIOMETRIC SURFACE MAP (OCTOBER 1980)**

LOCATION

Winnebago Reclamation Services, Rockford, IL.

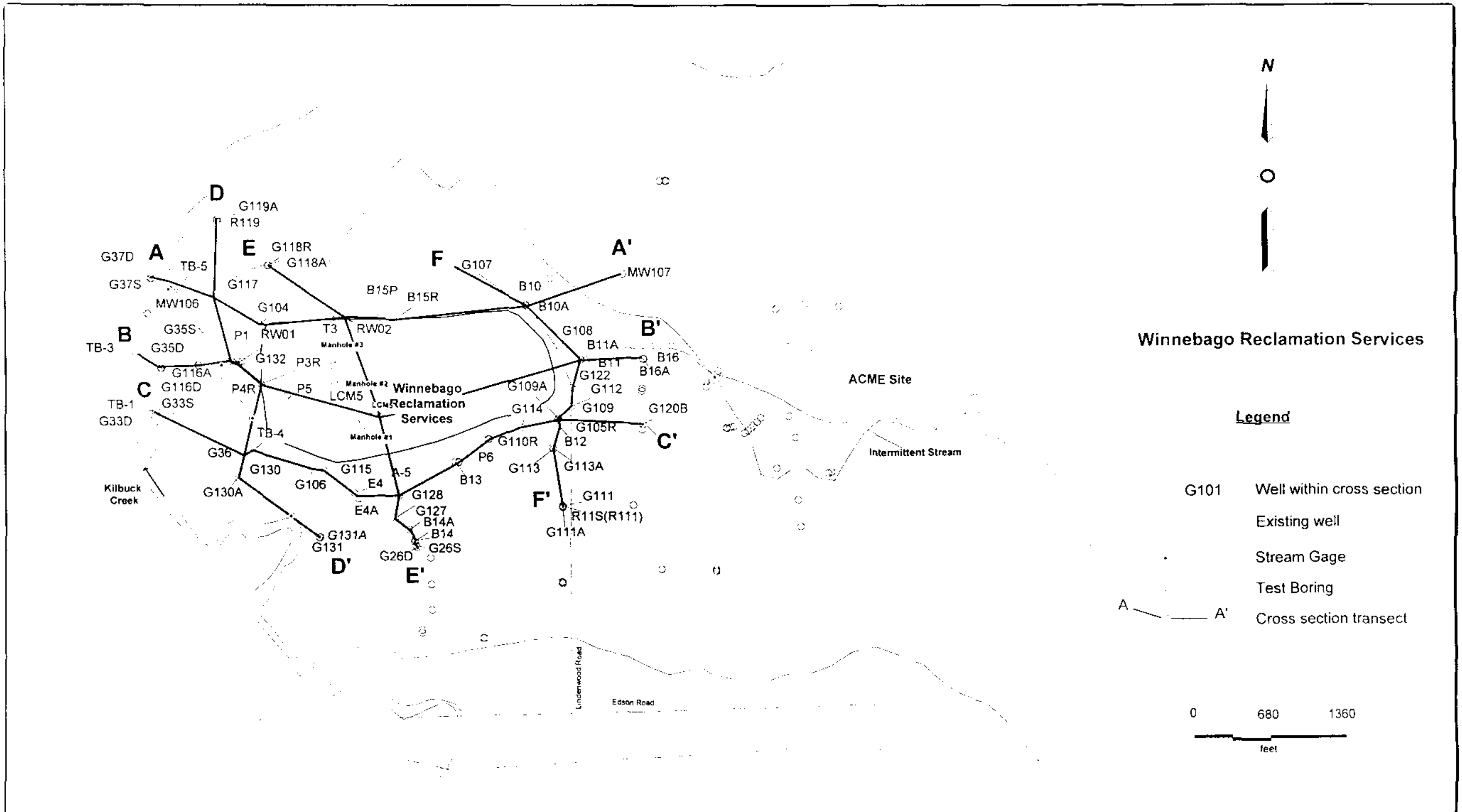
| | | | |
|---|---|---|---|
| GeoTrans, inc. GROUNDWATER SPECIALISTS | CHECKED | D.B. | FIGURE |
| | DRAFTED | P.K. | 2.7 |
| | FILE | 7735003A.DS4 | |
| | DATE | 6-9-95 | |

bedrock uplands, groundwater flow in the unconsolidated and upper bedrock aquifer system is expected to be to the east toward the Troy Bedrock Valley unconsolidated sediments. To the west of the bedrock uplands, groundwater flow is to the west toward the higher permeable sand deposits in the upper Rock Bedrock Valley (GeoTrans, 1995; Kay, 1991; Warzyn, 1991).

## 2.2 SITE-SPECIFIC HYDROGEOLOGY

This section provides a detailed discussion of the site-specific hydrogeology at and near the WRL site. Using the data collected during the extensive hydrogeologic field investigations from February 1995 to May 1995, hydrogeologic cross sections were constructed (Figures 2-8 to 2-14) to show hydrogeologic conditions in the study area. A compilation of bedrock surface elevations throughout the study area was performed to develop a detailed bedrock surface map of the study area (Figure 2-15). Potentiometric surface maps of the upper unconsolidated zone, lower unconsolidated zone, and bedrock zone are also presented (Figures 2-16 to 2-18). The details of these site-specific hydrogeologic features are discussed below.

In agreement with the regional geology, the local geology of the study area consists of high permeability Pleistocene unconsolidated glacial drift deposits overlying lower permeability Ordovician dolomite bedrock. The dolomite bedrock outcrops upgradient to the east of the WRL site and decreases in elevation to the west in the Upper Rock Bedrock Valley. The WRL site is present on the east edge of the Upper Rock Bedrock Valley. Several terraces have been identified in bedrock which indicated a north-south trend in the ancient fluvial depositional environment near the WRL (Staurowsky, 1991). The actual trend may be more complex as exhibited by the site-specific bedrock topographic surface map provided in Figure 3-8. Below the WRL site, the unconsolidated sediments form a clastic wedge that creates higher saturated thicknesses and corresponding higher transmissivities toward the west. A discussion of probable modes of deposition of the unconsolidated sediments in the study area is provided in Staurowsky (1991).



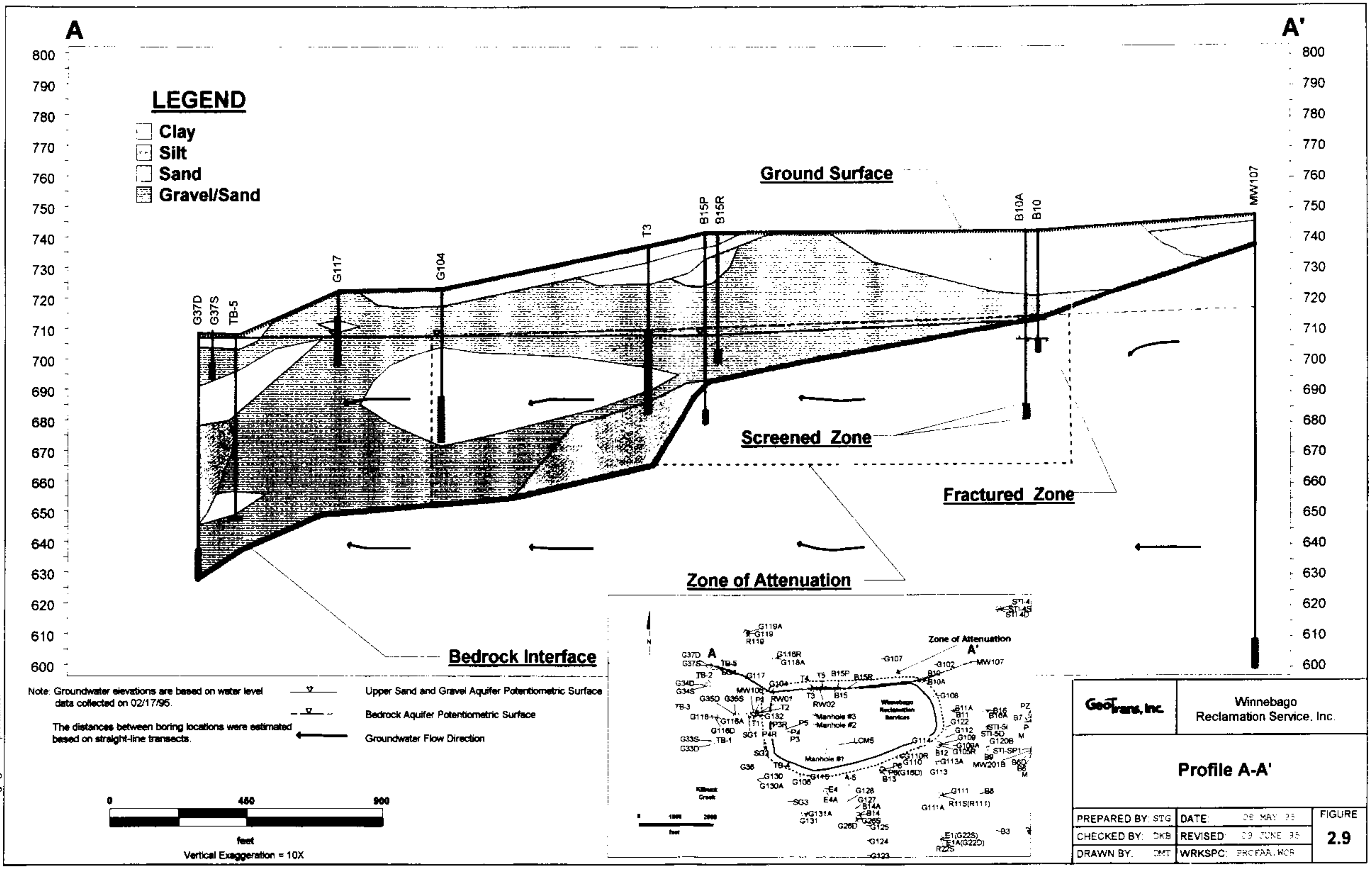

TITLE

## Cross Section Location Map

LOCATION
Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED | GCG | FIGURE |
| DRAFTED | AV | |
| FILE | cslm wor | 2-8 |
| DATE | 5-10-95 | |

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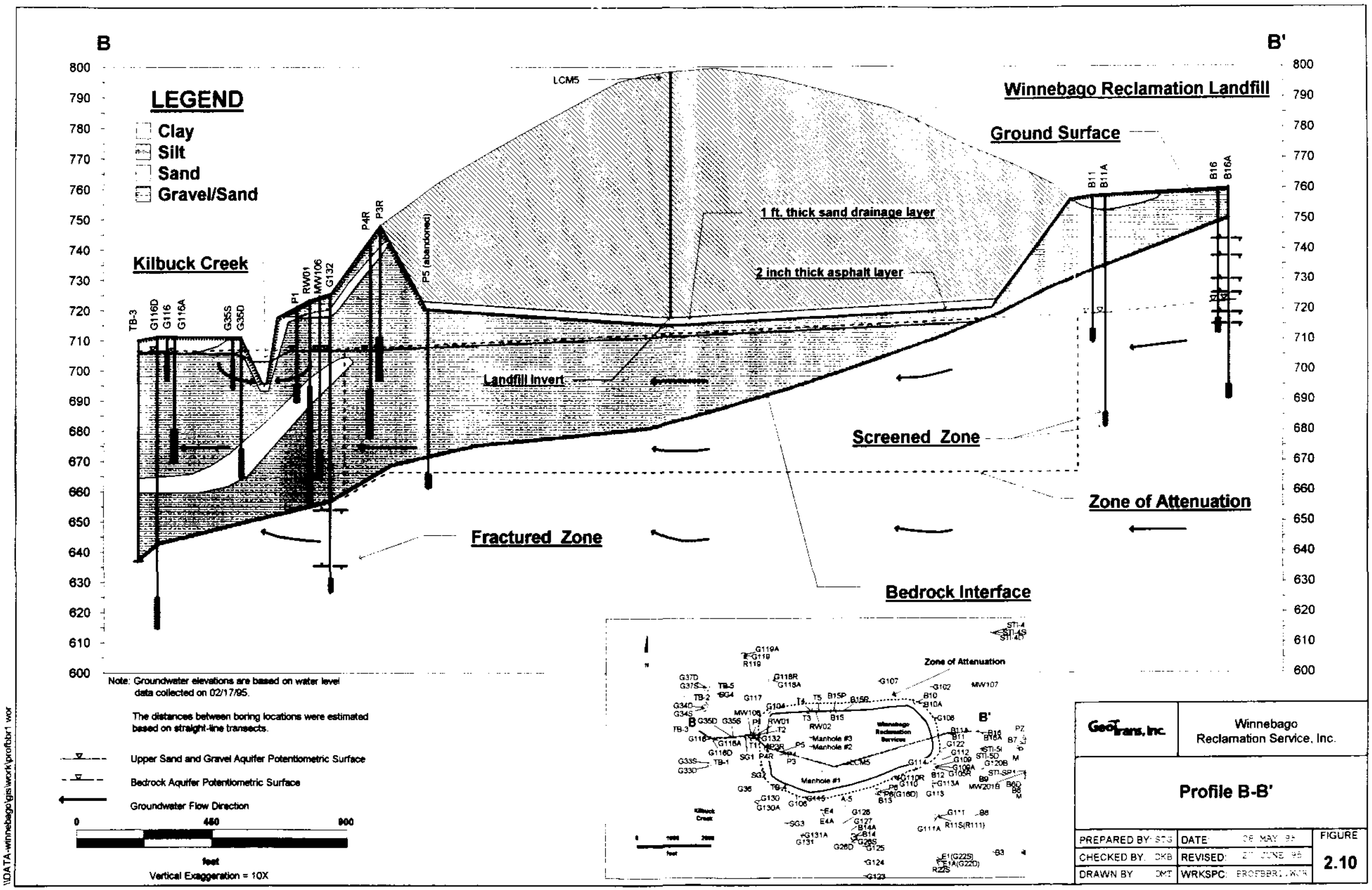
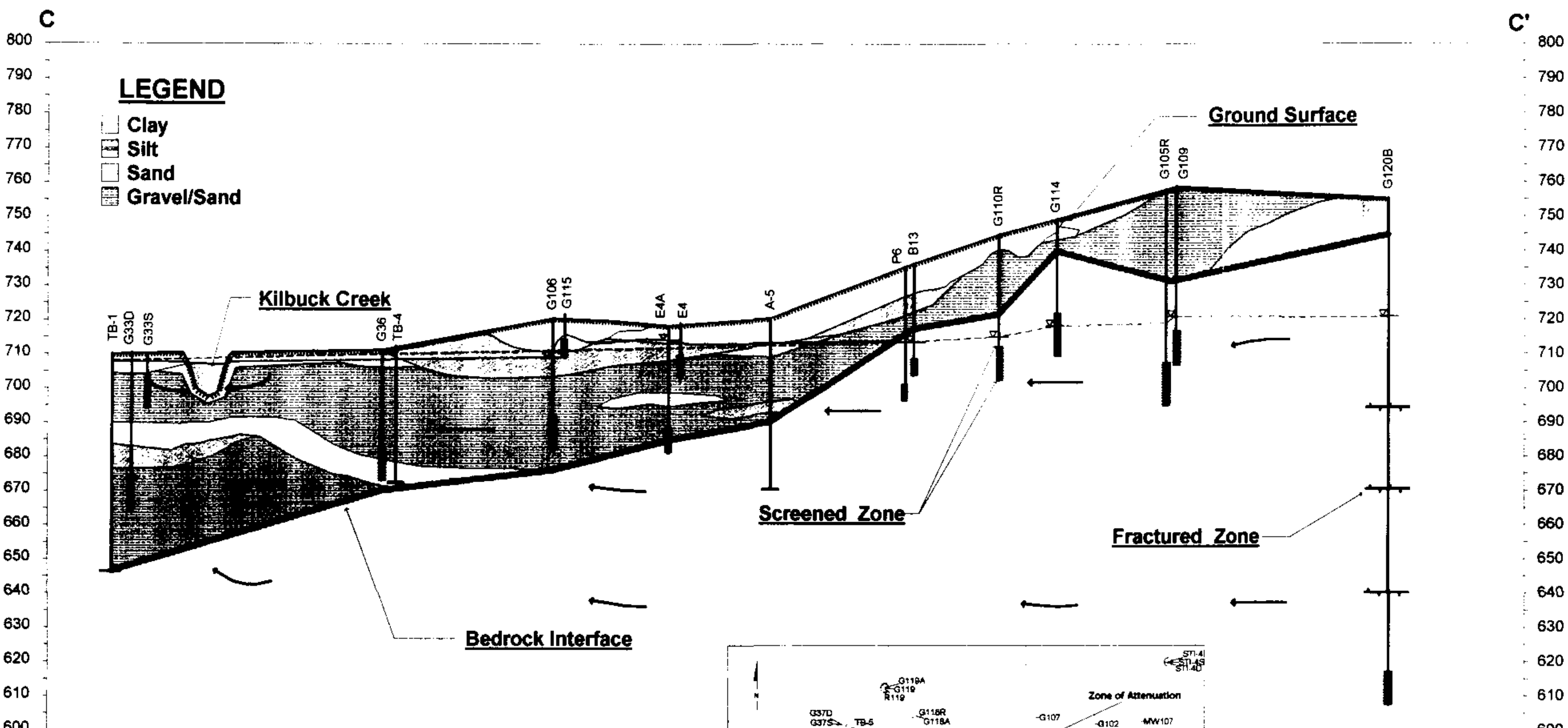


B
B'
Winnebago Reclamation Landfill
LEGEND
Clay
Silt
Sand
Gravel/Sand
Kilbuck Creek
Ground Surface
LCM5
1 ft. thick sand drainage layer
2 inch thick asphalt layer
Landfill Invert
Screened Zone
Zone of Attenuation
Fractured Zone
Bedrock Interface
TB-3
G116D
G116
G116A
G35S
G35D
P1
RW01
MW106
G132
P4R
P3R
P5 (abandoned)
B11
B11A
B16
B16A
800
790
780
770
760
750
740
730
720
710
700
690
680
670
660
650
640
630
620
610
600
Note: Groundwater elevations are based on water level data collected on 02/17/95.
The distances between boring locations were estimated based on straight-line transects.
Upper Sand and Gravel Aquifer Potentiometric Surface
Bedrock Aquifer Potentiometric Surface
Groundwater Flow Direction
0
450
900
feet
Vertical Exaggeration = 10X
Zone of Attenuation
Kilbuck Creek
Winnebago Reclamation Services
Manhole #1
Manhole #2
Manhole #3
GeoTrans, Inc.
Winnebago Reclamation Service, Inc.
Profile B-B'
PREPARED BY: STG
DATE: 26 MAY 95
CHECKED BY: DKB
REVISED: 27 JUNE 95
DRAWN BY: DMT
WRKSPC: PROFBBR1.WOR
FIGURE
2.10
\\DATA-winnebago\gis\work\profbbr1.wor




Note: Groundwater elevations are based on water level data collected on 02/17/95.

The distances between boring locations were estimated based on straight-line transects.

Upper Sand and Gravel Aquifer Potentiometric Surface

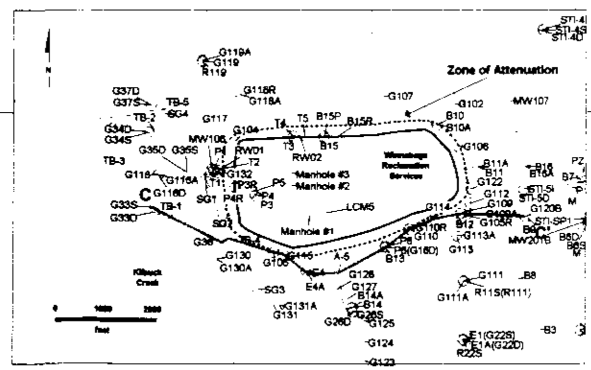
Bedrock Aquifer Potentiometric Surface

Groundwater Flow Direction

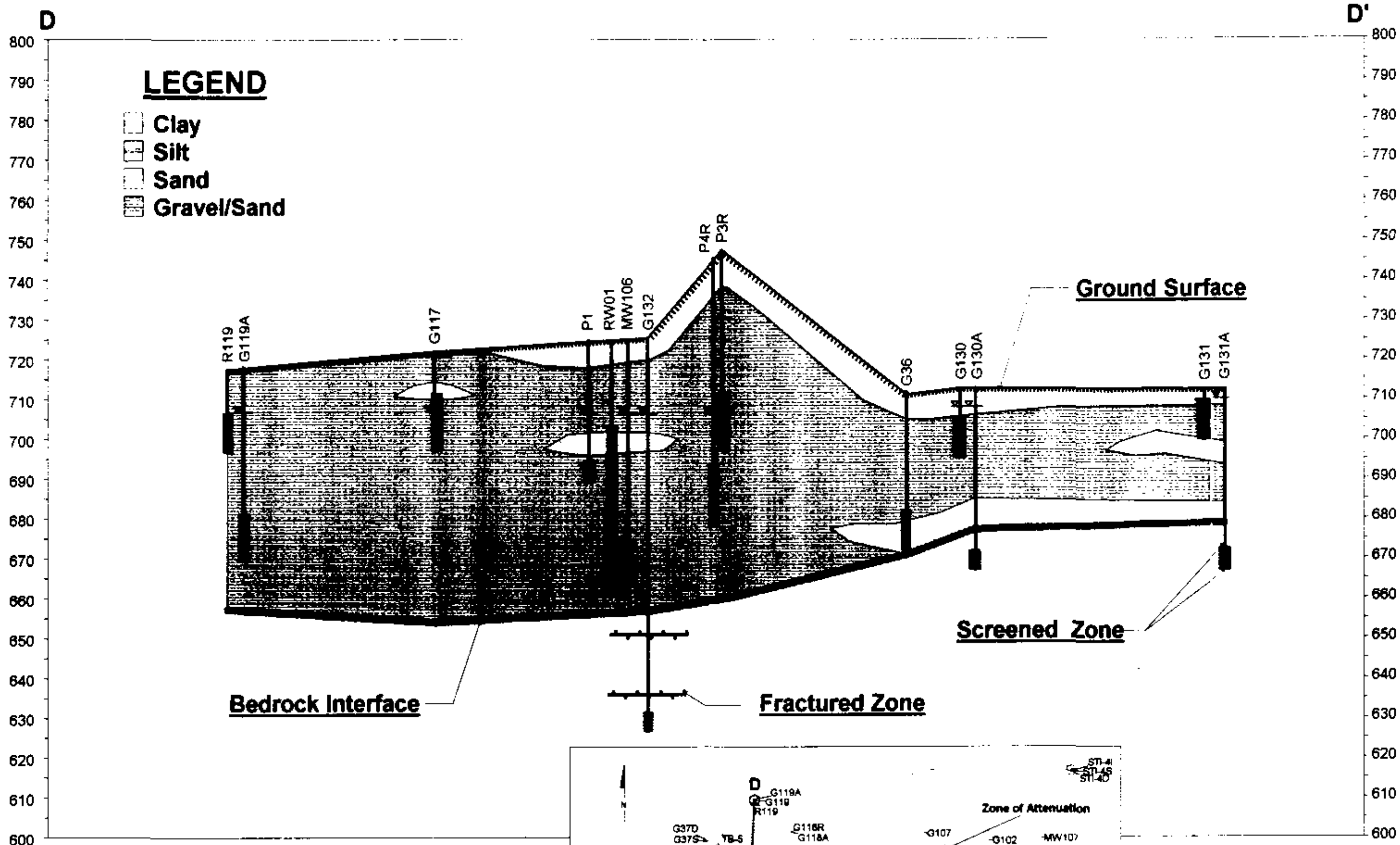
0 450 900

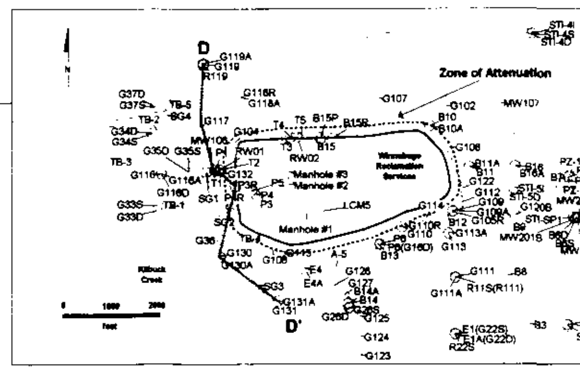
feet

Vertical Exaggeration = 10X




| GeoTrans, Inc. | Winnebago Reclamation Service, Inc | |
|---|---|---|
| | Profile C-C' | |
| PREPARED BY: STG | DATE: 08 MAY 95 | FIGURE |
| CHECKED BY: DKB | REVISED: 12 JUNE 95 | 2.11 |
| DRAWN BY: STG | WRKSPC: PROFCC.WOR | |




Note: Groundwater elevations are based on water level data collected on 02/17/95.

The distances between boring locations were estimated based on straight-line transects.

0 450 900

feet

Vertical Exaggeration = 10X

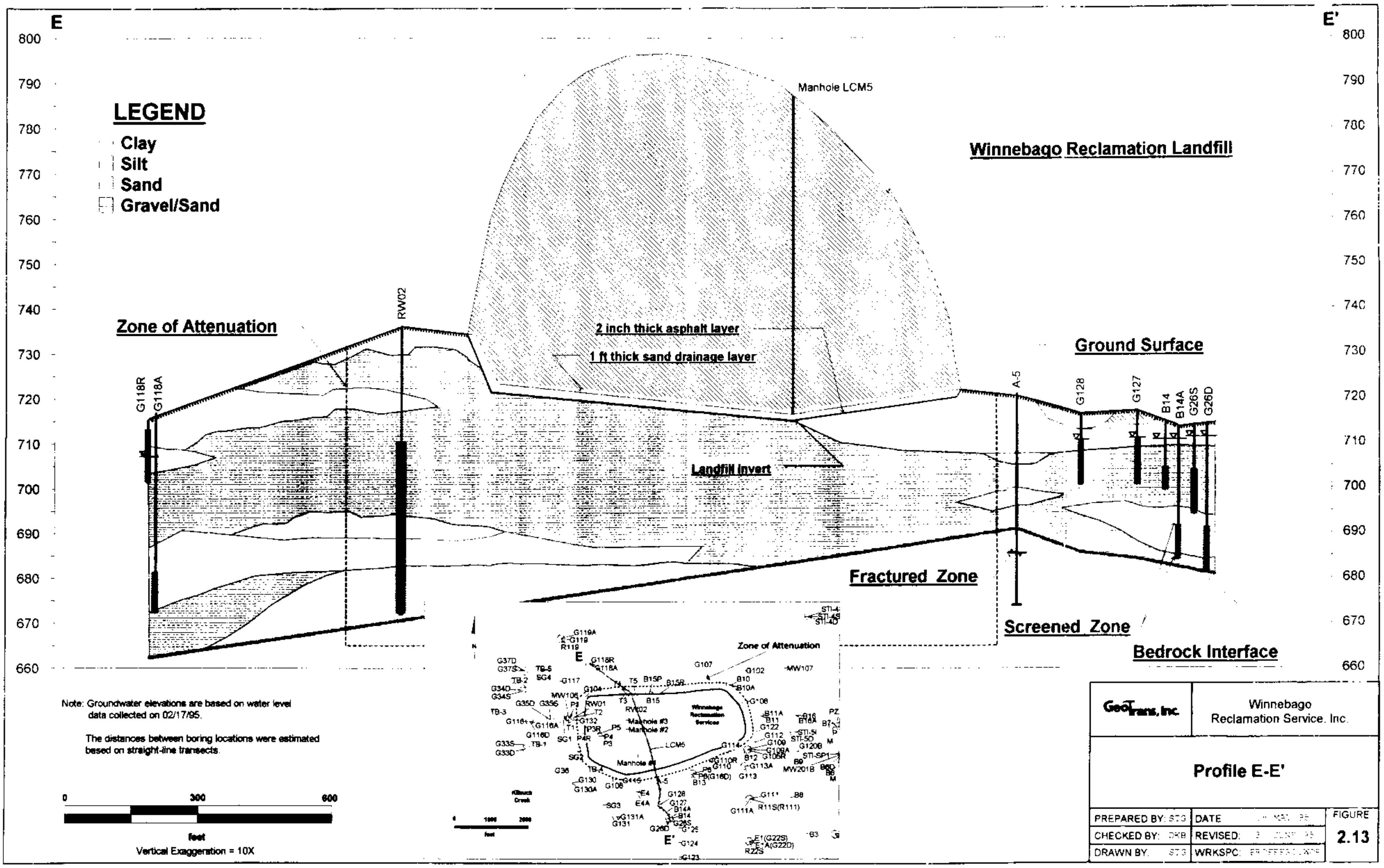
\\DATA-winnebago\gis\work\profdd.wor

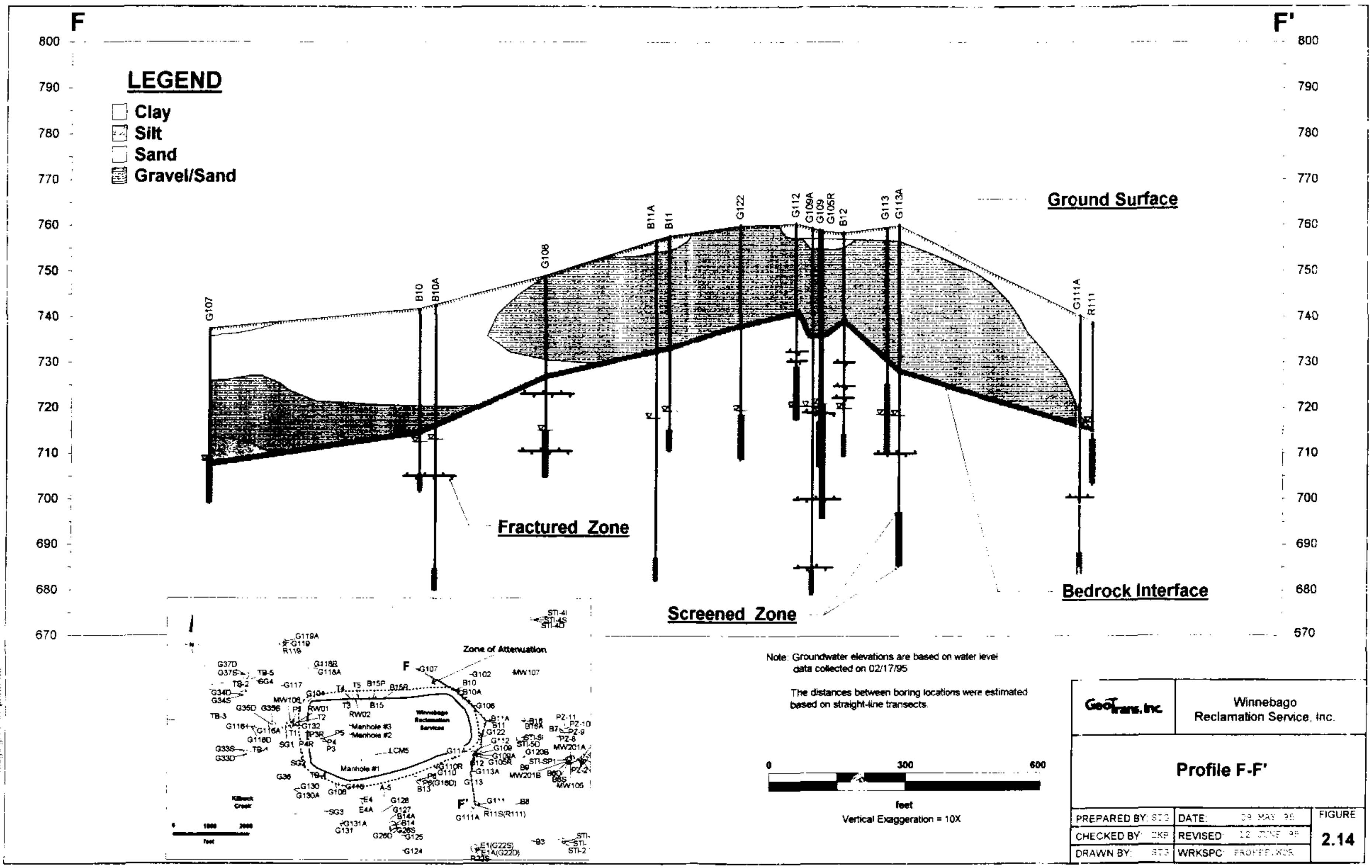
GeoTrans, Inc.

Winnebago Reclamation Service, Inc.

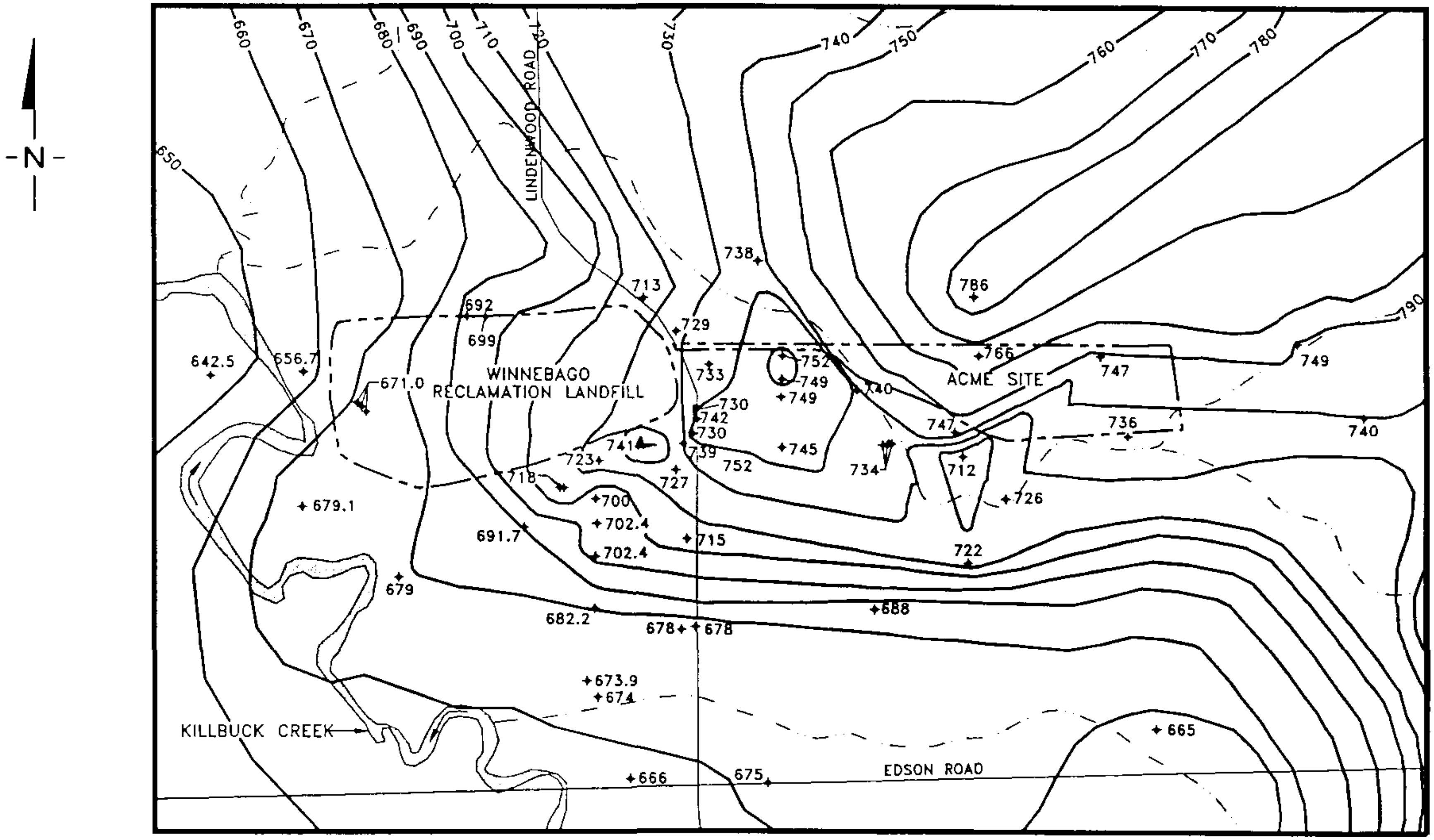
**Profile D-D'**

| | | |
|---|---|---|
| PREPARED BY: STG | DATE: 28 MAY 95 | FIGURE |
| CHECKED BY: DKB | REVISED: 12 JUNE 95 | 2.12 |
| DRAWN BY: STG | WRKSPC: PROFDD.WOR | |


E
E'
800
790
780
770
760
750
740
730
720
710
700
690
680
670
660
LEGEND
Clay
Silt
Sand
Gravel/Sand
Manhole LCM5
Winnebago Reclamation Landfill
Zone of Attenuation
RW02
2 inch thick asphalt layer
1 ft thick sand drainage layer
Ground Surface
G118R
G118A
A-5
G128
G127
B14
B14A
G26S
G26D
Landfill Invert
Fractured Zone
Screened Zone
Bedrock Interface
Zone of Attenuation
Note: Groundwater elevations are based on water level data collected on 02/17/95.
The distances between boring locations were estimated based on straight-line transects.
0
300
600
feet
Vertical Exaggeration = 10X
GeoTrans, Inc.
Winnebago Reclamation Service, Inc.
Profile E-E'
PREPARED BY:
CHECKED BY:
DRAWN BY:
DATE
REVISED:
WRKSPC:
FIGURE
2.13



F
F'
LEGEND
Clay
Silt
Sand
Gravel/Sand
Ground Surface
Fractured Zone
Screened Zone
Bedrock Interface
G107
B10
B10A
G108
B11A
B11
G122
G112
G109A
G109
G105R
B12
G113
G113A
G111A
R111
800
790
780
770
760
750
740
730
720
710
700
690
680
670
Zone of Attenuation
Note: Groundwater elevations are based on water level data collected on 02/17/95
The distances between boring locations were estimated based on straight-line transects.
0
300
600
feet
Vertical Exaggeration = 10X
GeoTrans, Inc.
Winnebago Reclamation Service, Inc.
Profile F-F'
PREPARED BY:
DATE:
CHECKED BY:
REVISED:
DRAWN BY:
WRKSPC:
FIGURE
2.14




LEGEND

| | |
|---|---|
| —706— | BEDROCK ELEVATION (FT MSL) |
| — - - — | WINNEBAGO RECLAMATION LANDFILL BOUNDARY |
| ✛ 706 | BEDROCK ELEVATION AND LOCATION |
| — — — | INTERMITTENT STREAM |

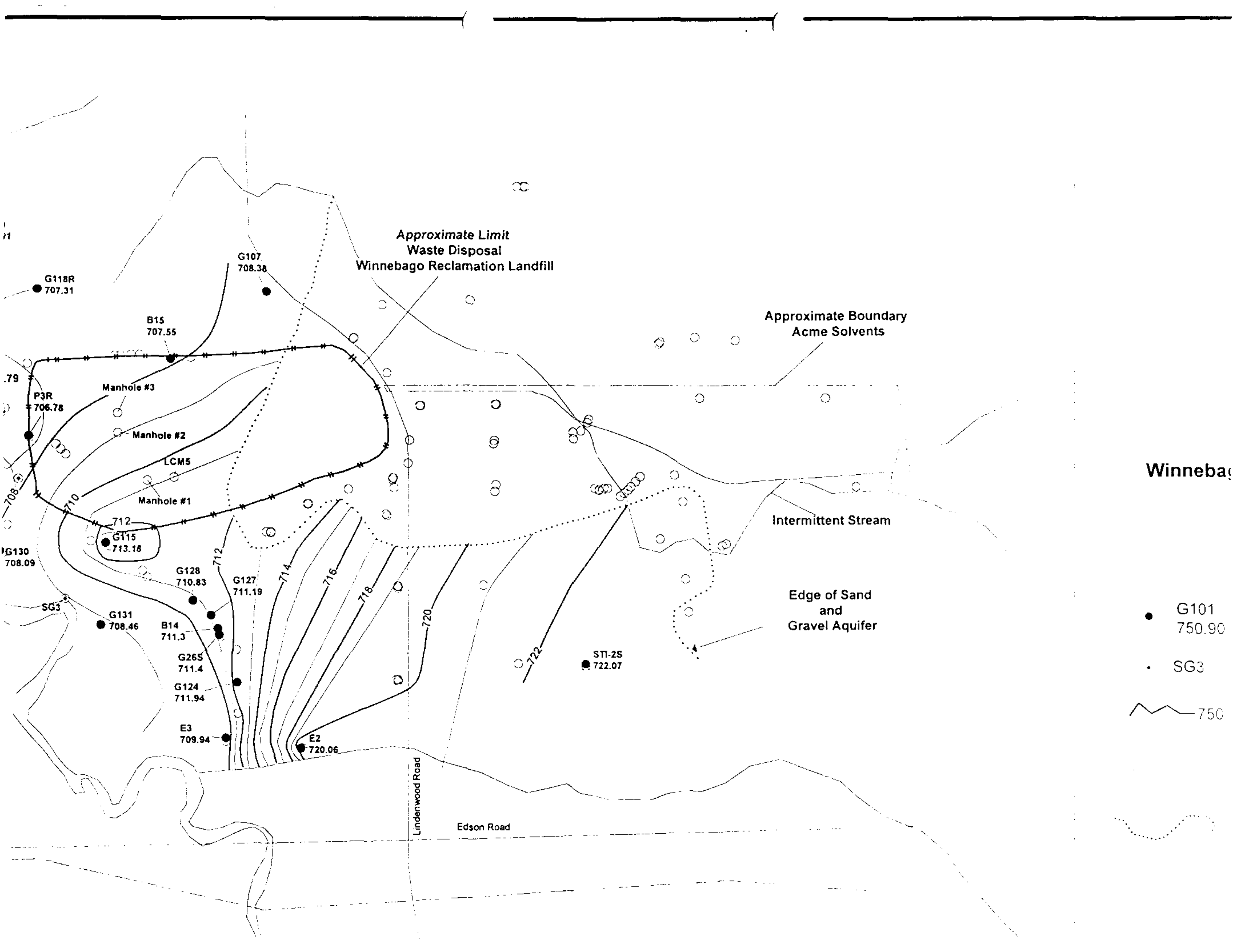
0 1000'
SCALE IN FEET

TITLE: LOCAL BEDROCK SURFACE ELEVATION MAP

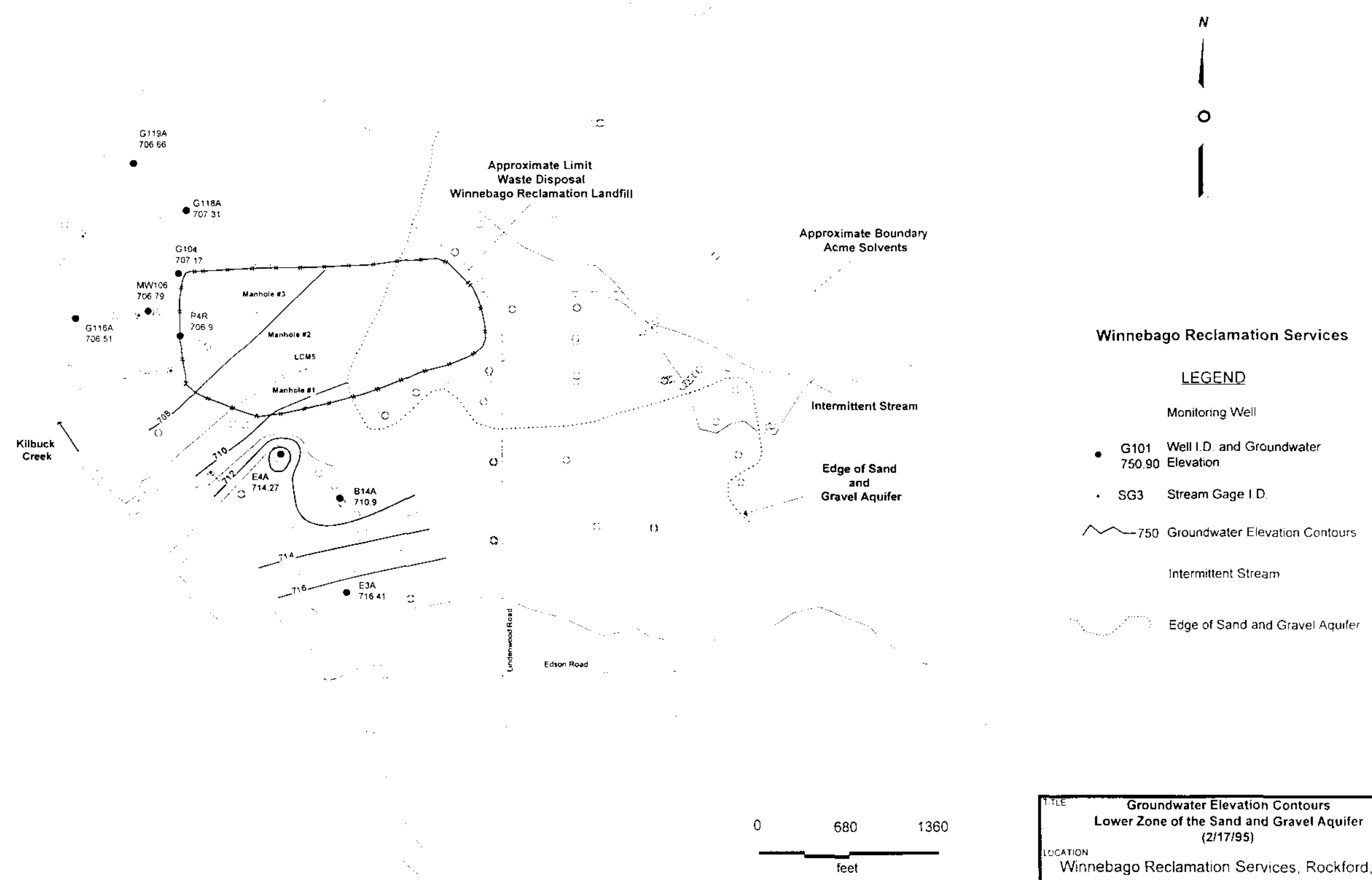
LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: |
| DRAFTED: | P.K. | 2-15 |
| FILE: | 7735014A | |
| DATE: | 7-7-95 | |



Approximate Limit
Waste Disposal
Winnebago Reclamation Landfill
Approximate Boundary
Acme Solvents
G107
708.38
G118R
707.31
B15
707.55
.79
P3R
706.78
Manhole #3
Manhole #2
LCM5
Manhole #1
708
710
712
G115
713.18
G130
708.09
SG3
G131
708.46
G128
710.83
G127
711.19
B14
711.3
G26S
711.4
G124
711.94
E3
709.94
E2
720.06
712
714
716
718
720
722
STI-2S
722.07
Intermittent Stream
Edge of Sand
and
Gravel Aquifer
Lindenwood Road
Edson Road
Winneba
G101
750.90
SG3
750

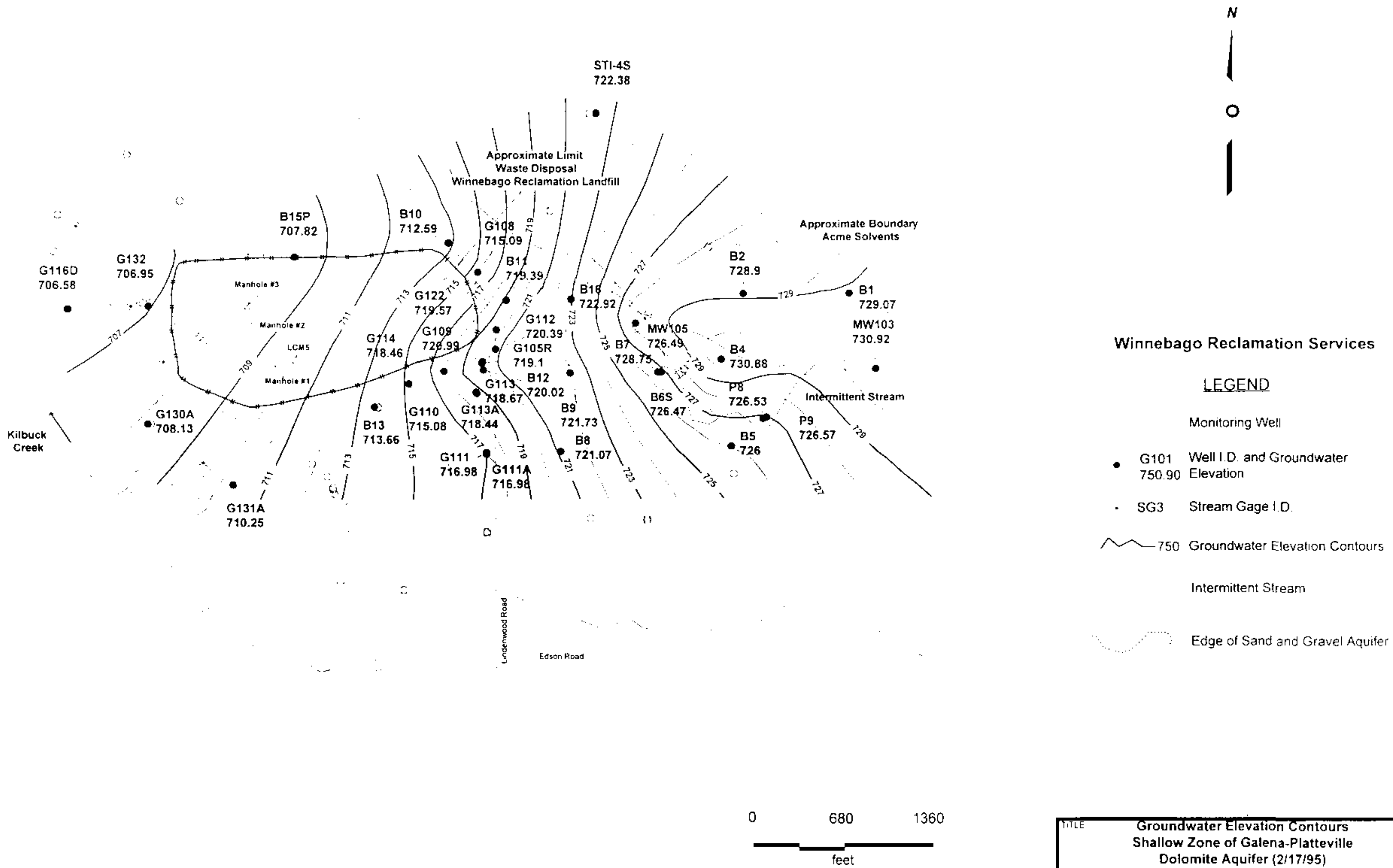



TITLE
**Groundwater Elevation Contours**
**Lower Zone of the Sand and Gravel Aquifer**
**(2/17/95)**

LOCATION
Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED | DB | FIGURE |
| DRAFTED | ELA | 2-17 |
| FILE | HR_316 WOR | |
| DATE | 9 MAY 1995 | |




TITLE
**Groundwater Elevation Contours Shallow Zone of Galena-Platteville Dolomite Aquifer (2/17/95)**

LOCATION
Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | | |
|---|---|---|---|
| CHECKED | DB | FIGURE | |
| DRAFTED | ELA | | 2-18 |
| FILE | HR_317.WOR | | |
| DATE | 9 MAY 1995 | | |

Based on the large number of soil borings drilled and logged in the study area, six hydrogeologic cross sections are presented along the transects (see Figure 2-8). These cross sections clearly show the westward slope in bedrock beneath the WRL site that was discussed above. Along some of these cross section transects, a thin veneer of Cahokia clays, silts, and sands are present near Kilbuck Creek. The higher permeable sand and gravel deposits of the Mackinaw Member of the Henry Formation are shown along transects in the west part of the study area. On the eastern portion of the WRL site, the cross sections show the poorly sorted ice-contact deposits of the Wasco Member of the Henry Formation. Thick deposits of lower permeability clays and silts are present both south of the WRL near G111 (transect F-F') and northwest of Kilbuck near G37 (transect A-A'). These clay sediments are tentatively identified as part of the Esmond Member of the Glasford Formation based on lithology. In the upper bedrock, transects B-B' and C-C' show the inherent bedrock fractures that are present to the east of the WRL site.

In agreement with the regional groundwater flow characteristics discussed above, the site-specific surficial hydrostratigraphy consists of the Pleistocene sand and gravel aquifer and the Galena-Platteville dolomite bedrock aquifer. These aquifers are well connected and form the unconsolidated and upper bedrock surficial aquifer system. Unconfined conditions are present in the bedrock uplands where only bedrock is saturated and west of the Acme site where the unconsolidated sediments become saturated. Below the saturated unconsolidated sediments, the bedrock aquifer is unconfined to semi-confined with a generally higher piezometric head than the water table. This indicates that groundwater in the lower permeable dolomite has the potential to flow upward into the higher permeability sand and gravel aquifer.

### 2.2.1 SAND AND GRAVEL AQUIFER

The Pleistocene aquifer saturated thickness varies from zero feet on the east side of the WRL site where bedrock outcrops to 80 feet at G37 located northwest of the WRL. In the study area, the Pleistocene sand and gravel aquifer consists of high permeability sand and gravel outwash deposits of the Mackinaw Member of the Henry Formation, and ice-contact deposits of the Wasco Member of the Henry Formation. To the northwest and south of the WRL, lower permeability clay aquitards are present which create local semi-confined conditions within the sand and gravel aquifer.

The hydraulic properties of each hydrostratigraphic unit at the WRL site have been characterized through pumping, bail-down, slug, and laboratory tests to estimate hydraulic conductivity within the hydrostratigraphic units. A seven hour aquifer pumping test was performed at RW-01 using a pumping rate of 130 gpm. The resulting maximum drawdown at each of the observation wells was only 0.5 feet. A detailed analysis of this aquifer test indicates that the hydraulic conductivity of the sand and gravel aquifer is 1500 ft/day. Slug testing of wells screened in the sand and gravel aquifer indicate that the hydraulic conductivity varies from less than 0.5 ft/day in higher clay content areas to greater than 1000 ft/day in gravel zones. It should be noted that the results of the pumping test are more reliable indicators of average aquifer permeability than slug tests because pumping tests evaluate a significantly greater volume of aquifer material. Results of laboratory tests for total porosity for the sand and gravel aquifer sediments are provided in Table 3.1.

Groundwater flow is primarily vertical through low permeability aquitards, and therefore, the vertical hydraulic conductivity is the most important hydraulic parameter for an aquitard. During the field investigations from March to May, 1995, Shelby tube samples were collected from the thick clay sediments present west-northwest of the study area at the G34 and G37 well clusters (see Figure 2-9). These sediments create locally confined groundwater conditions in the lower zone of the sand and gravel aquifer. The hydraulic conductivity of these samples was analyzed using laboratory permeability tests. The results of these analyses indicated that the vertical hydraulic conductivity of the clay aquitard was 0.00037 ft/day to 0.0045 ft/day.

An examination of the potentiometric surface maps (Figures 2.16 to 2.18) shows that groundwater in the sand and gravel aquifer generally flows to the west-northwest in the study area. Shallow groundwater discharges to Kilbuck Creek. Deeper groundwater flows beneath Kilbuck Creek toward the northwest. Along different groundwater flow pathways, the average horizontal hydraulic gradient varies from 0.003 to 0.009 ft/day (GeoTrans, 1995c).

Based on observed gradients and hydraulic conductivities, the average linear velocity in the sand and gravel aquifer is approximately 25 ft/day.

### 2.2.2 DOLOMITE BEDROCK AQUIFER

Site-specific studies indicate that the Galena and Platteville Groups form the dolomite bedrock aquifer beneath the study area (HLA, 1990; Warzyn, 1991). The dolomite bedrock aquifer saturated thickness is approximately 225 feet in the study area. The dolomite bedrock aquifer is recharged primarily in the bedrock uplands via precipitation events. Additional recharge to the Galena-Platteville aquifer occurs due to leakage from the intermittent stream located west of the WRL site.

The hydraulic properties of the Galena-Platteville dolomite bedrock aquifer have been characterized through several studies (HLA, 1990; Warzyn, 1991; GeoTrans, 1995). Warzyn performed slug tests on four bedrock wells using air pressure. The analysis methods and results of these slug tests are provided in the RI/FS report (Warzyn, 1991). Pumping tests of the bedrock aquifer were performed in 1990 (HLA, 1990). Production tests were recently performed on potential recovery wells for a groundwater remediation system (summer 1995 start date) at the Acme Solvents site. Recently, air pressure slug tests were performed in a few wells screened in the dolomite bedrock aquifer. The details of the analysis procedures and results are provided in GeoTrans (1995a). Based on these aquifer tests, the hydraulic conductivity of the dolomite bedrock aquifer varies from 0.001 to 68 ft/day. These pumping tests also indicated the presence of a low permeability zone at the Acme Solvent site. It should be noted that a high permeability zone is also present between the Acme Solvent site and the WRL site based on observed fracture zones and low hydraulic gradients. This high permeability zone is described in detail in the RI/FS report (Warzyn, 1991).

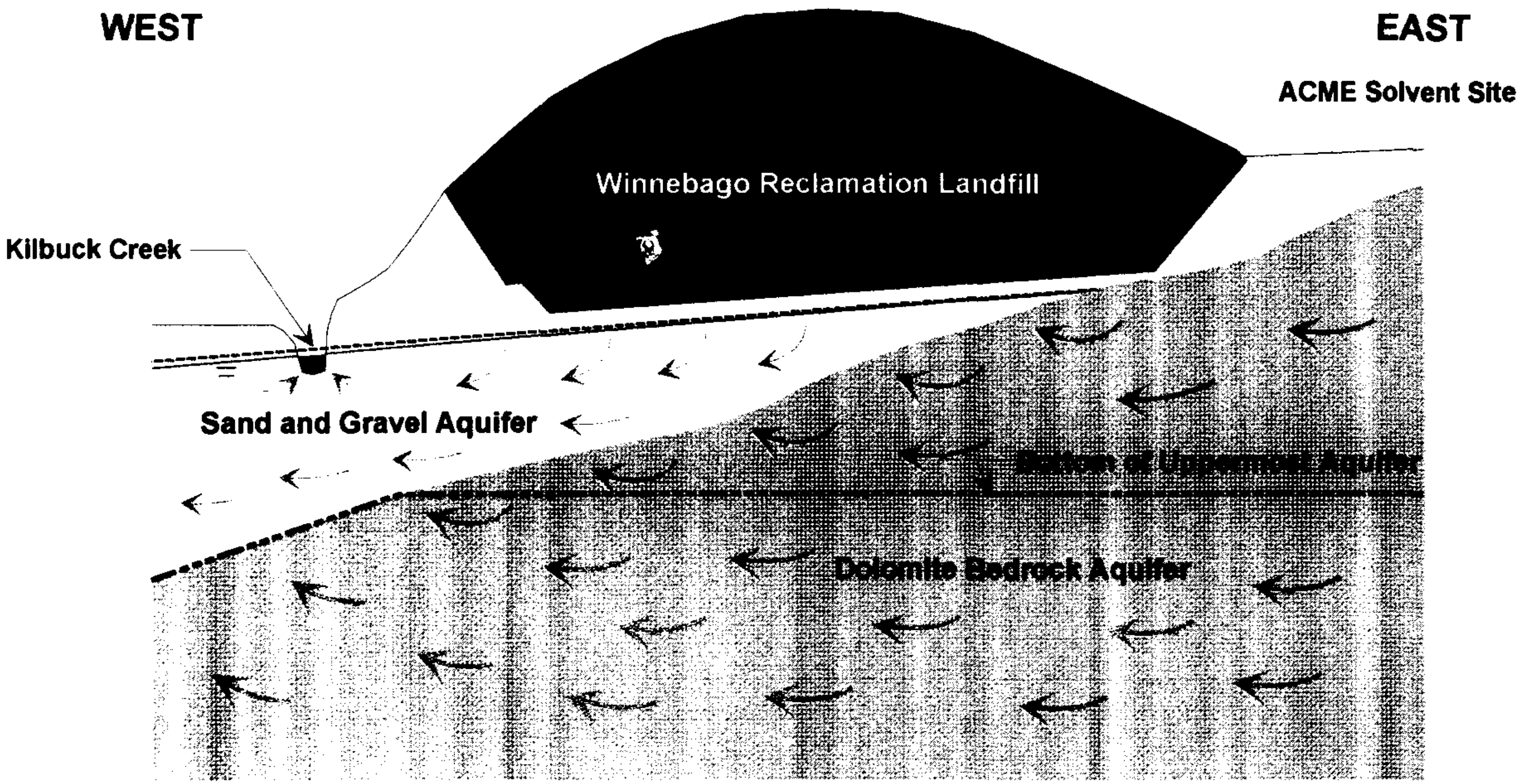
Potentiometric surface maps (Figures 3-9 to 3-20) show that groundwater flow in the dolomite bedrock aquifer is generally to the west in the study area. Shallow bedrock groundwater flows upward into the higher permeability sand and gravel sediments. Deeper bedrock groundwater flows beneath Kilbuck toward the west. The presence of groundwater mounding at the Acme Solvent site may be caused by both recharge from the intermittent stream and the localized low permeability zone. Based on observed gradients and hydraulic conductivities, the average linear velocity in the dolomite bedrock aquifer is approximately 0.001 to 6.8 ft/day.

### 2.2.3 UNCONSOLIDATED AND BEDROCK AQUIFER SYSTEM

As stated earlier in Section 2.1.2, the unconsolidated and Galena-Platteville dolomite sediments form a regional unconsolidated and upper bedrock aquifer system. Detailed studies at the WRL site show a site-specific hydrostratigraphic setting which is consistent with this regional interpretation. Figure 2-19 shows a generalized cross section of the hydrogeologic conditions at the WRL site based on the substantial amount of hydrogeologic data collected in the study area. This figure shows that groundwater flow in the unconsolidated and upper bedrock aquifer system is generally toward the west-northwest. In areas where only bedrock is saturated, groundwater flows downward in these bedrock upland sediments. However, in areas where the sand and gravel sediments are saturated, bedrock groundwater flows upward back into these higher permeability sand and gravel deposits. This interpretation is supported by the: 1) historical potentiometric surface maps (GeoTrans, 1995a); 2) presence of elevated levels of chlorinated compounds in bedrock at the upgradient Acme Solvent Superfund Site (HLA, 1990); and 3) by the absence of landfill leachate-related constituents in bedrock at the WRL site (GeoTrans, 1995b).

### 2.2.4 BASAL CONFINING UNIT

The basal confining unit at and near the WRL site is the Glenwood Formation. As stated above, the Glenwood Formation generally consists of interbedded carbonates, sandstone, and shale. The lithology of the Glenwood Formation is highly variable both vertically and laterally. The carbonates are light gray to green and lithographic to finely crystalline. The sandstones within this formation are fine- to coarse-grained with well-rounded quartzose sand. The shales are generally gray-green to blue-green, and occur as thin partings within the sandstones and carbonates. At soil boring STI-DC1, located at the Acme




**Legend**

sand and gravel potentiometeric surface
---------- bedrock potentiometeric surface
—-----— bottom of uppermost aquifer

Not drawn to scale

TITLE
**GENERALIZED CROSS SECTION OF HYDROGEOLOGIC CONDITIONS AT THE WRL SITE**

LOCATION
Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED | D.B. | FIGURE |
| DRAFTED | P.K. | 2.19 |
| FILE | 7735001A.DS4 | |
| DATE | 6-20-95 | |

Solvent site, the Glenwood Formation is 36 feet thick and is moderately to little fractured except for the extensive fracturing in its basal beds. Based on lithology, the permeability of the Glenwood Formation is expected to be low with minor amounts of groundwater flow through this basal confining unit.

# 3 FLOW MODEL CONSTRUCTION

The simulation program MODFLOW was used to develop a numerical groundwater flow model for the WRL. The primary phases in the development of a numerical groundwater flow model include: 1) the construction of a finite-difference grid for the model area; 2) specification of model layer top and bottom elevations; 3) assignment of boundary conditions; 4) specification of hydraulic parameter values and zones; and 5) selection of appropriate water-level measurements for calibration of the model. This information forms the basis for subsequent calibration of the numerical model to observed groundwater flow conditions at the site.

## 3.1 CODE SELECTION AND DESCRIPTION

For the simulation of groundwater flow at the WRL site, MODFLOW, a publicly available groundwater flow simulation program developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988) was selected. MODFLOW is thoroughly documented, widely used by consultants, government agencies, and researchers, and is consistently accepted in regulatory and litigation proceedings. Given the ultimate intended use for the WRL groundwater flow model as a remedial decision-making tool, regulatory acceptance is vital for the code selected for this study.

In addition to its attributes of widespread use and acceptance, MODFLOW was chosen because of its versatile simulation features. MODFLOW can simulate transient or steady-state saturated groundwater flow in one, two, or three dimensions and offers a variety of boundary conditions including specified head, areal recharge, injection or extraction wells, evapotranspiration, drains, and rivers or streams. Aquifers simulated by MODFLOW can be confined or unconfined, or convertible between confined and unconfined conditions. For the WRL site, which consists of a multiaquifer system with variable hydrogeologic unit thicknesses and boundary conditions, MODFLOW's three-dimensional capability and boundary condition versatility are essential for the proper simulation of groundwater flow conditions.

MODFLOW simulates transient, three-dimensional groundwater flow through porous media described by the following partial differential equation for a constant density fluid:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) - W = S_s\frac{\partial h}{\partial t} \qquad (3\text{-}1)$$

where:

| | | |
|---|---|---|
| $\mathbf{K_{xx}}$, $\mathbf{K_{yy}}$ and $\mathbf{K_{zz}}$ | = | values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity [L/T]; |
| **h** | = | the potentiometric head [L]; |
| **W** | = | a volumetric flux per unit volume and represents sources and/or sinks of water [1/T]; |
| $\mathbf{S_s}$ | = | the specific storage of the porous material [1/L]; and |
| **t** | = | time [T]; |

In equation (3-1), the hydraulic parameters (i.e., $K_{xx}$, $K_{yy}$, $K_{zz}$ and $S_s$) may vary in space but not in time; the source/sink (W) terms may vary in both space and time.

To solve the partial differential groundwater flow equation (3-1) on a computer, MODFLOW uses a numerical approximation technique known as the method of finite differences. Using a block-centered finite-difference approach, MODFLOW replaces the continuous system represented in equation (3-1) by a set of discrete points in space and time. This process of discretization ultimately leads to a system of simultaneous linear algebraic equations. MODFLOW solves these finite-difference equations with one of the following three iterative solution techniques: strongly implicit procedure (SIP), slice-successive over-relaxation (SSOR), or preconditioned conjugate gradients (PCG). The solution of the finite-difference equations produces time-varying values of head at each of the discrete points representing the real aquifer system. Given a sufficient number of discrete points, the simulated values of head yield close approximations of the head distributions given by exact analytical solutions to equation (3-1).

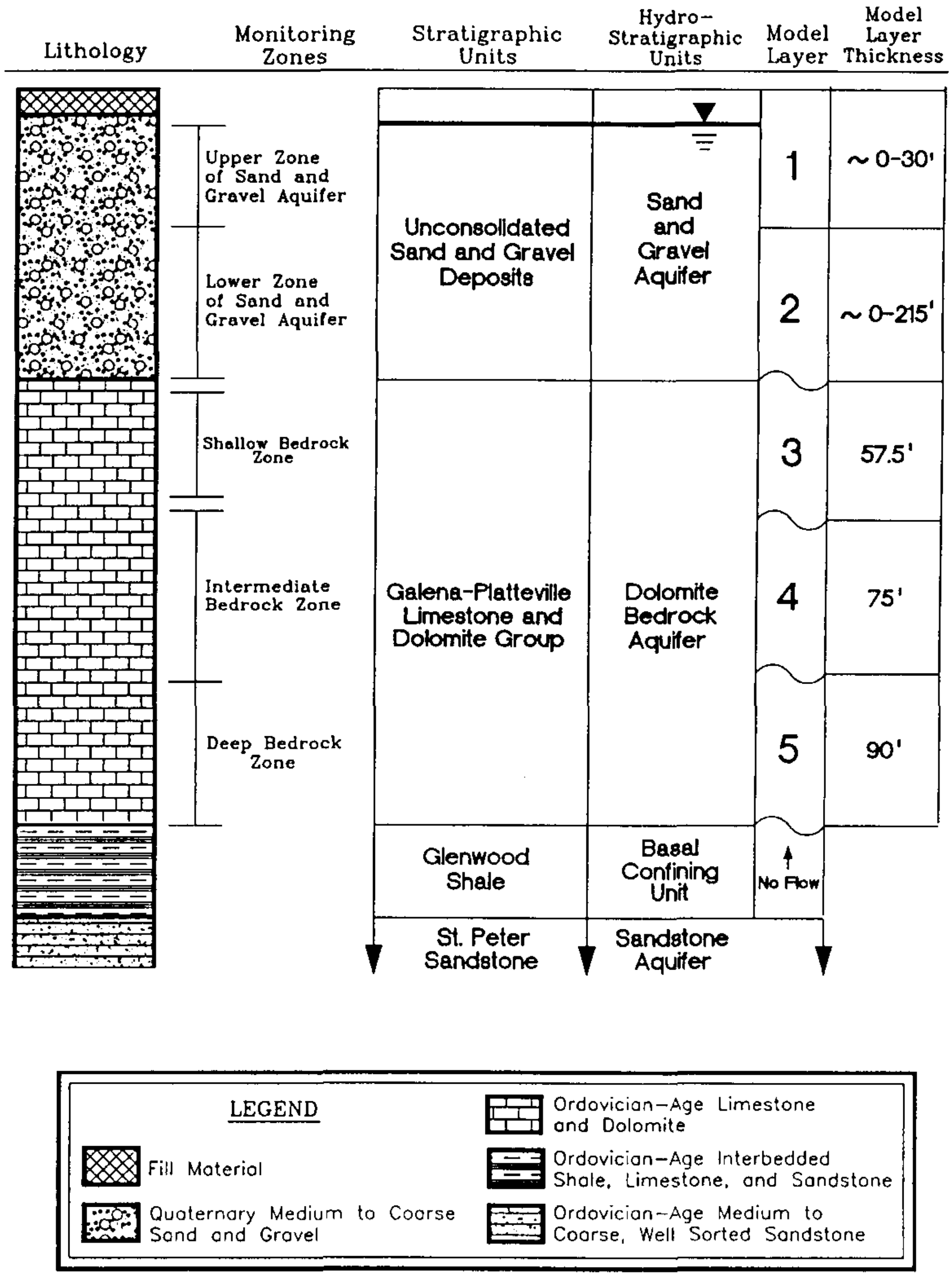
## 3.2 Model Discretization

The finite-difference technique employed in MODFLOW to simulate hydraulic head distributions in multiaquifer systems requires areal and vertical discretization or subdivision of the continuous aquifer system into a set of discrete blocks that form a three-dimensional model grid. In the block-centered finite-difference formulation used in MODFLOW, the center of each grid block corresponds to a computational point or node. When MODFLOW solves the set of linear algebraic finite-difference equations for the complete set of blocks, the solution yields values of hydraulic head at each node in the three-dimensional grid.

Water levels computed for each block represent an average water level over the volume of the block. Thus, adequate discretization (i.e., a sufficiently fine grid) is required to resolve features of interest, and yet not be computationally burdensome. MODFLOW allows the use of variable grid spacing such that a model may have a finer grid in areas of interest where greater accuracy is required and a coarser grid in areas requiring less detail.

Because groundwater flow at the WRL site is primarily horizontal in the aquifers and vertical through the aquitards, the model designed by GeoTrans simulates vertical groundwater flow through the aquitard using a quasi-three-dimensional approach. In this approach, only aquifers are vertically discretized as layers in the model; aquitards are represented by leakance coefficients, which regulate the amount of vertical flow between aquifers. Based on the hydrostratigraphy at the site, GeoTrans used two layers of vertical discretization to simulate flow in the sand and gravel aquifer and three layers to simulate flow in bedrock. The flow model represents the: 1) upper sand and gravel; 2) lower sand and gravel; 3) upper bedrock; 4) intermediate bedrock; and 5) lower bedrock by model layers 1, 2, 3, 4 and 5, respectively (Figure 3-1).

The three-dimensional model grid developed for the WRL site covers approximately 4.2 square miles (Figure 3-1). The boundaries of the model grid were specified to coincide with natural hydrogeologic boundaries when possible and to minimize the influence




TITLE: GENERALIZED HYDROSTRATIGRAPHIC COLUMN AND CORRESPONDING MODEL LAYERS.

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: 3-1 |
| DRAFTED: | C.S. | |
| FILE: | 7735FMA | |
| DATE: | 6-29-95 | |

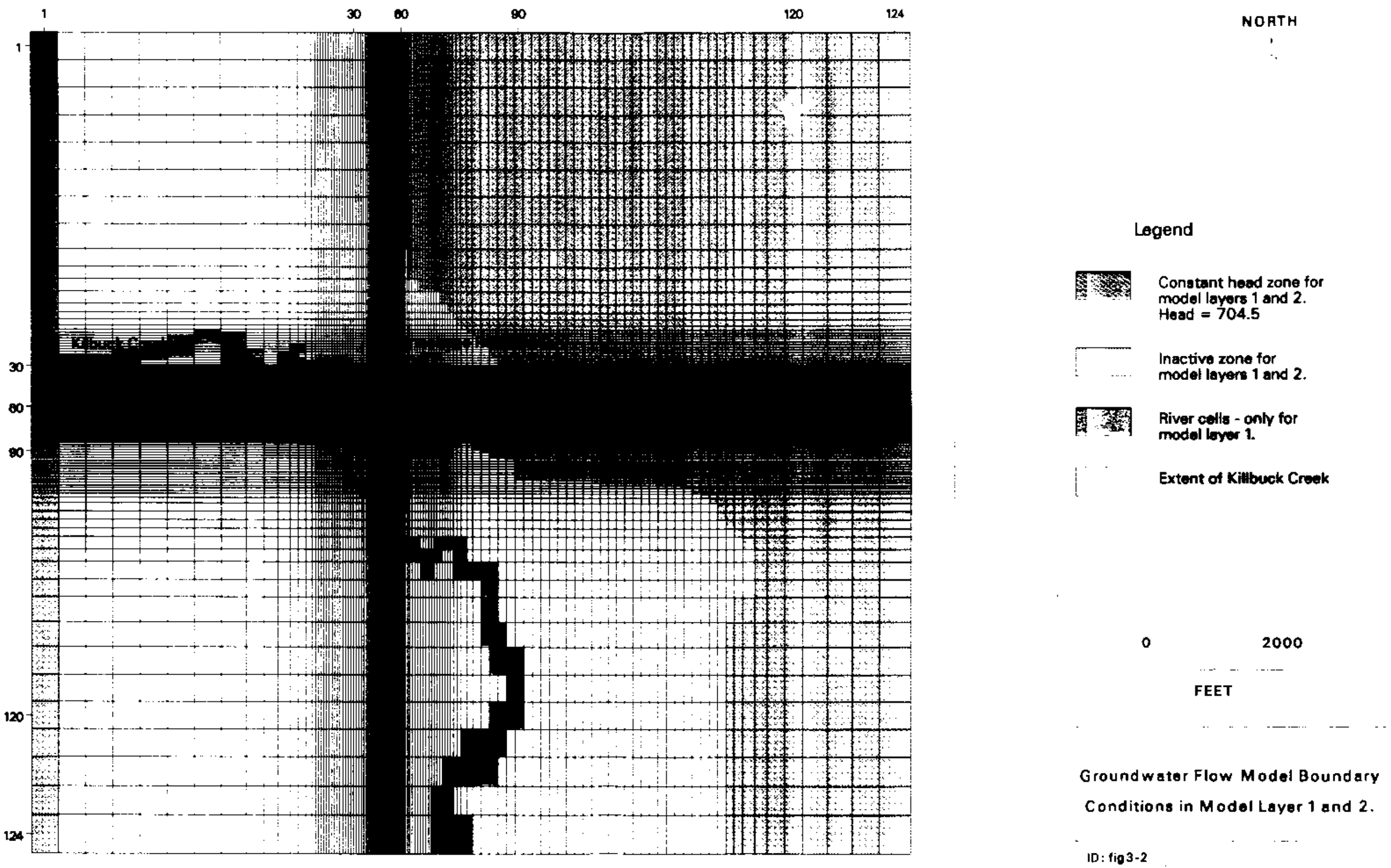
of model boundaries on simulation results at the site. The model domain is approximately 2.2 miles along the east-west boundary and 1.9 miles along the north-south boundary. The finite-difference grid is composed of 115 columns by 124 rows with five vertical layers for a total of 42,780 nodes. The model grid uses a 20-foot areal grid spacing in the area of the site to provide increased computational detail in the area of interest and grades to larger grid spacing at greater distances from the site.

The extent of the finite-difference grid and the 20-ft areal grid spacing used at the downgradient edge of the WRL site were selected for the purpose of simulating both regional groundwater flow conditions around the site, and sufficiently detailed hydraulic head distributions near the site. The extent chosen for the grid ensured adequate incorporation of regional groundwater flow features that affect conditions at the site. The areal grid spacing specified near the WRL site allowed a sufficiently detailed simulation of hydraulic heads to match water levels and groundwater flow directions measured at the site. Meeting both of these objectives was essential for the calibration of the three-dimensional groundwater flow model.

### 3.3 BOUNDARY CONDITIONS

External model boundaries were chosen to coincide with the regional flow directions of the unconsolidated and upper bedrock aquifer system. The groundwater flow model boundary conditions for each model layer are discussed below. The simulated boundary conditions vary according to hydraulic conditions encountered in each layer and are also discussed in detail below.

Along the east and west boundaries of the model, we assigned constant head boundary conditions to represent groundwater inflow and outflow to and from each aquifer (layer) of the model (Figure 3-2 and 3-3). The constant head values were estimated based on observed vertical and horizontal hydraulic gradients in the vicinity of each model boundary. Since regional groundwater flow is primarily east to west, no-flow boundary conditions were specified on the northern and southern model boundaries to correspond with regional flow lines.




Groundwater Flow Model Boundary Conditions in Model Layer 1 and 2.

ID: fig3-2

DATE: 7/3/95

BY: mcb

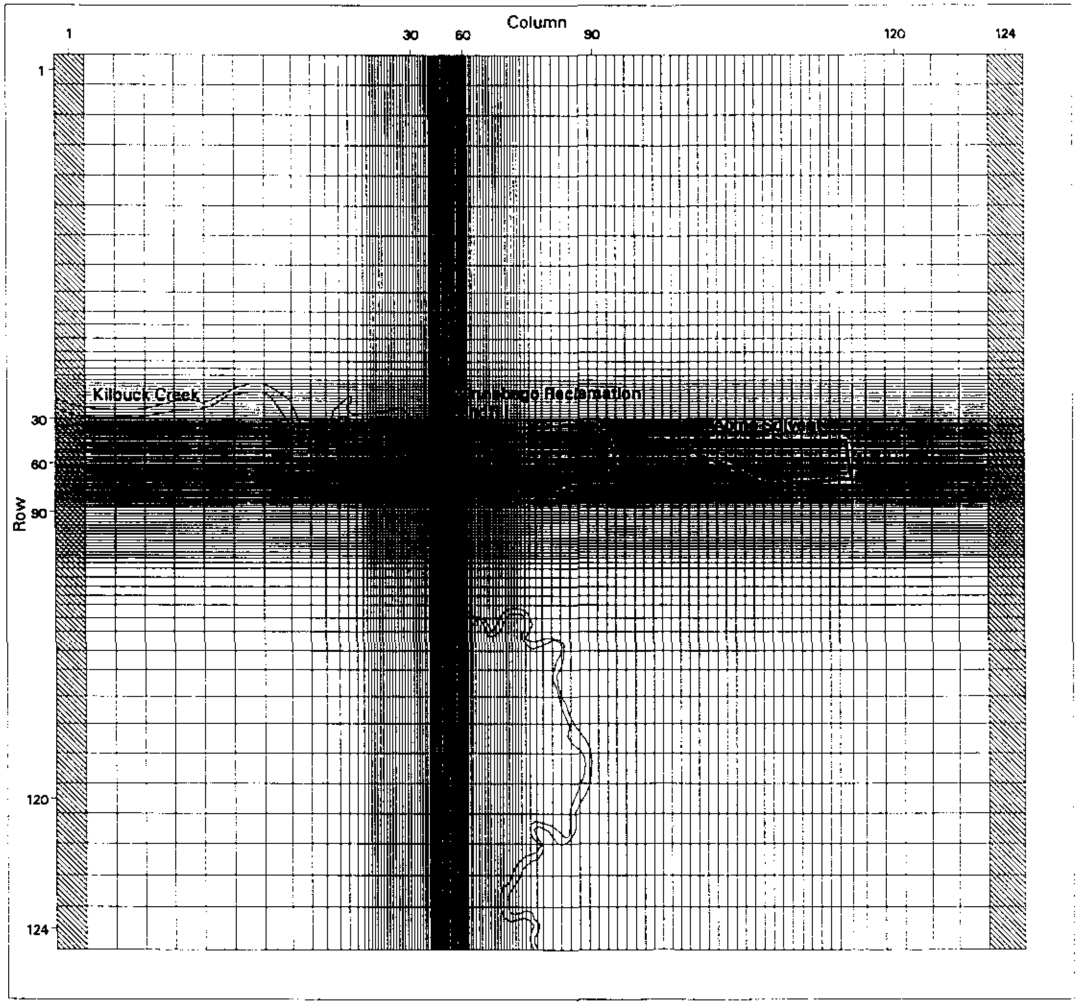
FIGURE 3-2

River boundary conditions were specified in model layer 1 to represent Kilbuck Creek (Figure 3-2). The river stage elevation for these river cells was assigned based on observed elevations at several stream gages (SG-1 through SG-4) on February 17, 1995. River stage elevations were estimated between these points using linear interpolation. The conductance of surface water bottom sediments in each river cell was calculated based on the length of reach in each cell, the width of each surface water feature, a bottom sediment thickness of one foot, and a bottom sediment hydraulic conductivity equal to 0.1 ft/day at each cell.

An extensive amount of regional (Visocky, 1985; Berg, 1984; Hackett, 1960) and site-specific (Warzyn, 1991a) hydrogeologic data were used to construct regional structural contour elevation maps of the distinct zones of both the unconsolidated and bedrock aquifers. The contours of these maps were then digitized and interpolated values were specified for each corresponding cell in the model grid in order to define the vertical discretization of model layers. The elevations of each layer (aquifer) in the numerical model are shown in Figures 3-4 through 3-8.

## 3.4 HYDRAULIC PARAMETERS

In constructing the model for the WRL site, representative values for model parameters were chosen based on site-specific data. These model parameters included aquifer recharge rate, horizontal and vertical hydraulic conductivity of the aquifers, and vertical hydraulic conductivity of the aquitard. Initially, a uniform recharge rate was assigned in the model to represent the fraction of total precipitation reaching the water table. The model also included separate initial values of hydraulic conductivity in the unconsolidated and bedrock aquifers based on the more reliable site-specific pump test data. Vertical hydraulic conductivities in the model had a nonuniform initial distribution to represent heterogeneity. During the calibration of the model, the values of these parameters were adjusted to minimize the error between observed and simulated groundwater elevations at target locations.




NORTH

## Legend

Constant head zone for model layers 3, 4, and 5.

| | Column 1 | Column 124 |
|---|---|---|
| Layer 3 | 704.61 | 733.00 |
| Layer 4 | 704.68 | 732.97 |
| Layer 5 | 705.70 | 732.54 |

0 2000
FEET

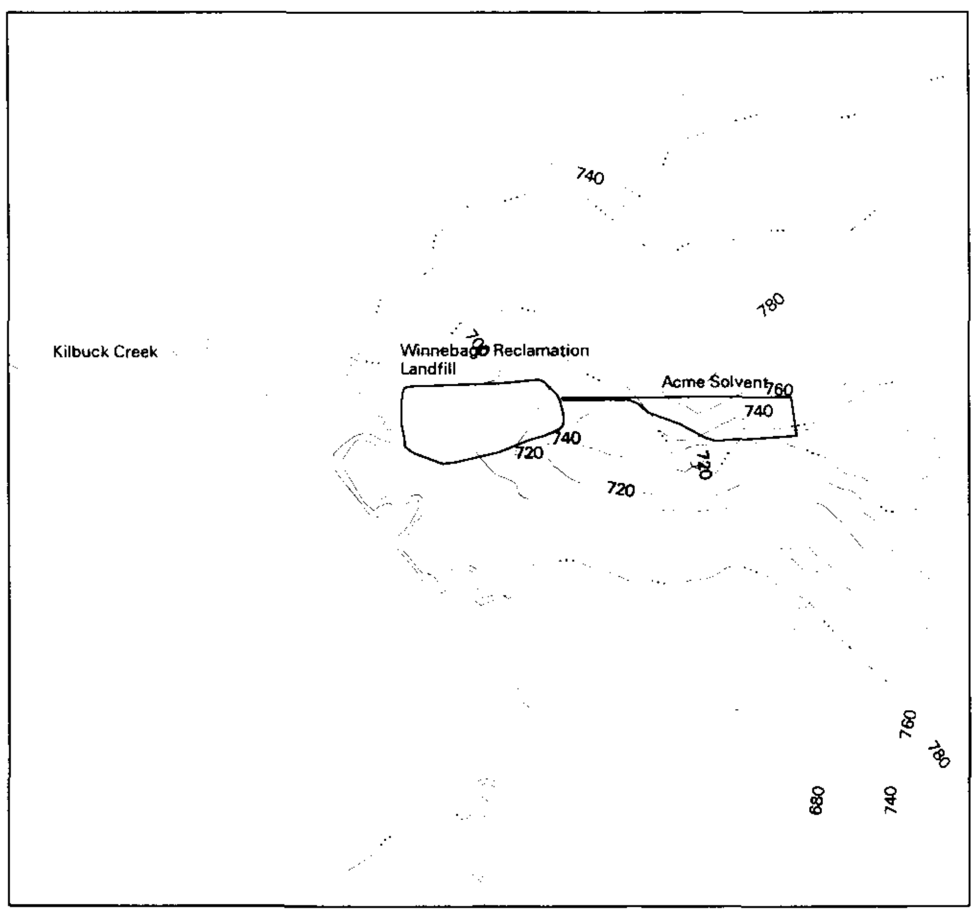
Groundwater Flow Model Boundary Conditions in Model Layer 3, 4, and 5.

ID: fig3-3

DATE: 7/3/95

BY: mcb

FIGURE 3-3




Top Elevation of Model Layer 2.

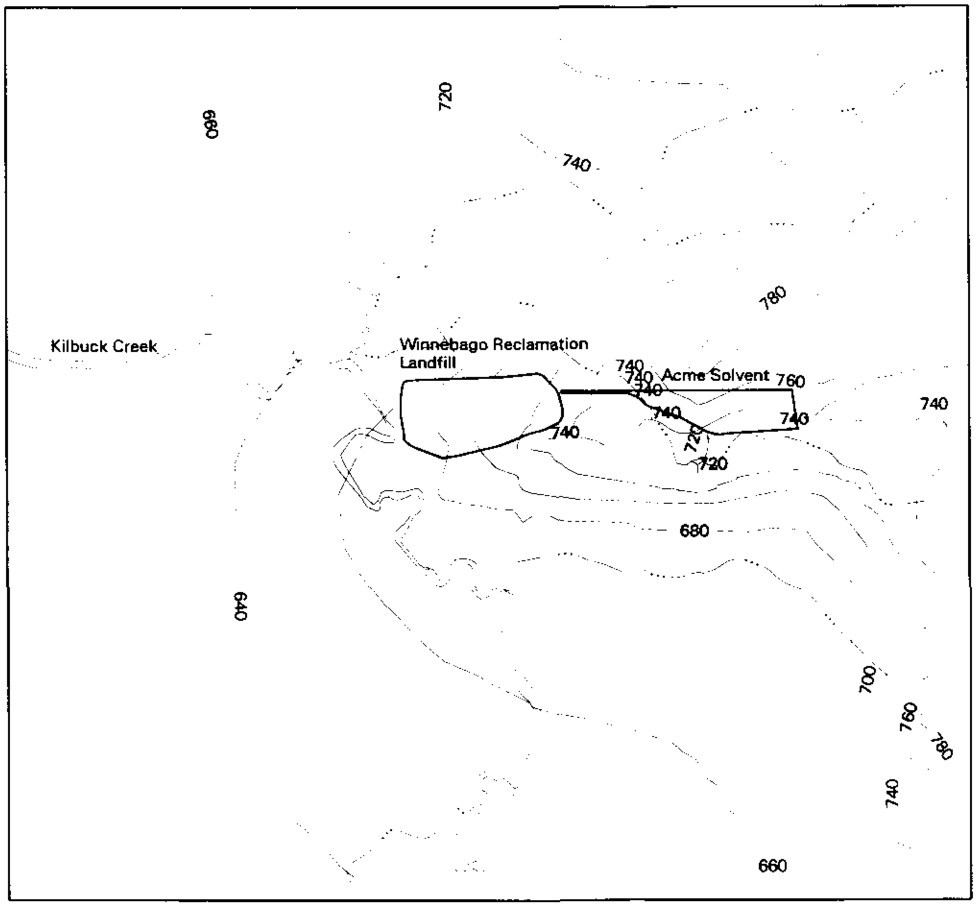
ID: top2

DATE: 7/3/95

BY: mcb

FIGURE

3-4




Top Elevation of Model Layer 3.

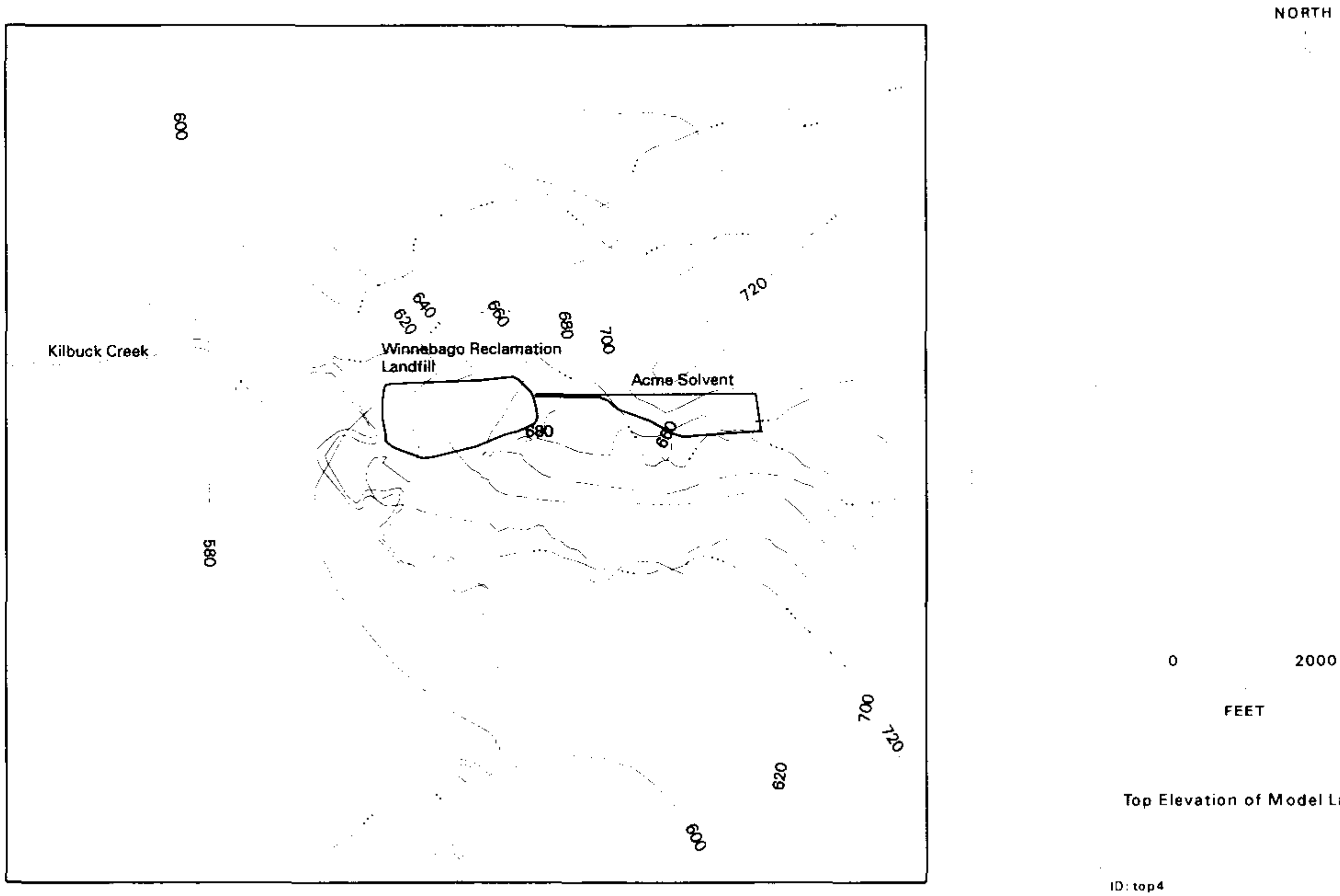
ID: top3

DATE: 7/3/95

BY: mcb

FIGURE

3-5




Top Elevation of Model Layer 4.

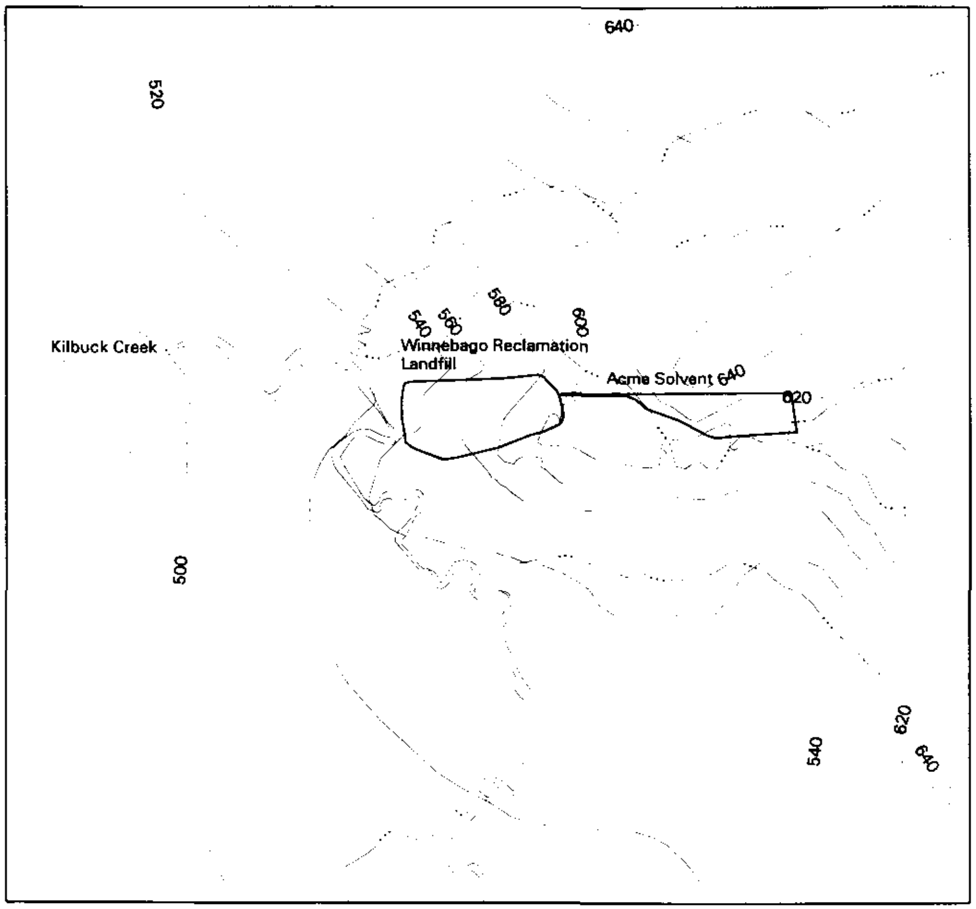
ID: top4

DATE: 7/3/95

BY: mcb

FIGURE

3-6




Top Elevation of Model Layer 5.

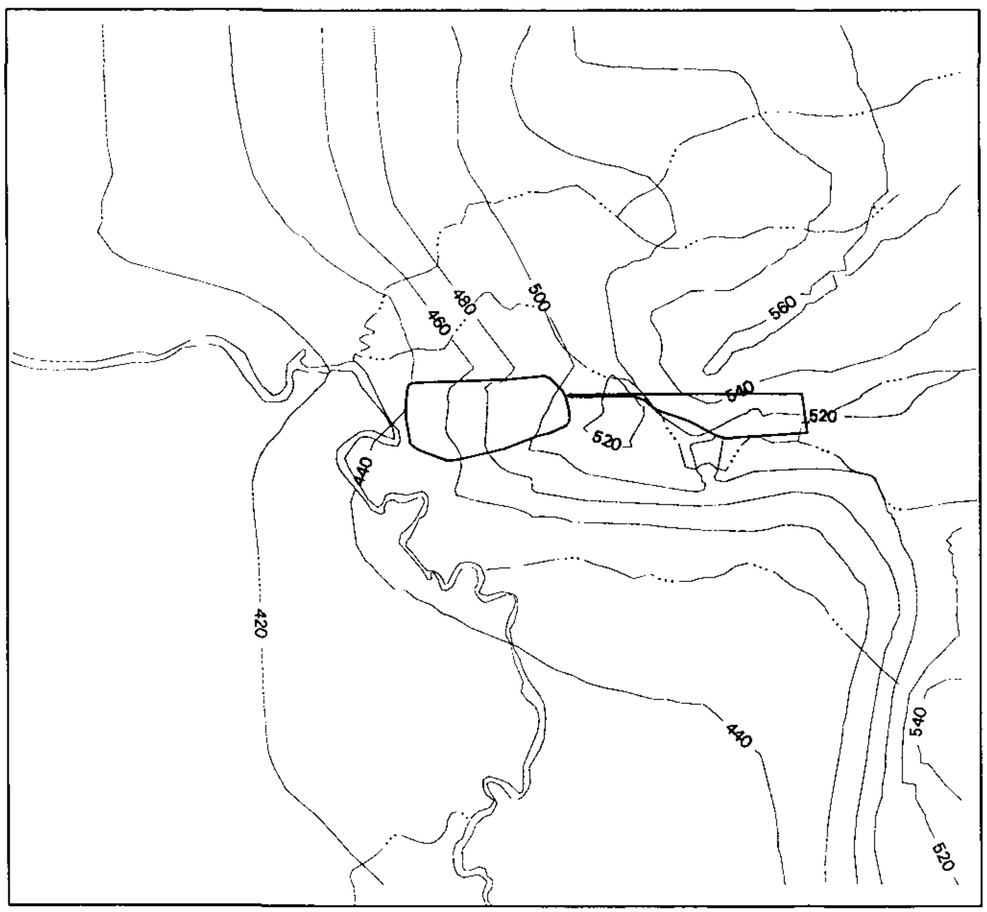
ID: top5

DATE: 7/3/95

BY: mcb

FIGURE

3-7




BOTTOM ELEVATION OF MODEL LAYER 5.

ID: bot5

DATE: 2/8/95

BY: mcb

FIGURE 3-8.

## 3.5 CALIBRATION TARGETS

Calibration targets are a set of field measurements, typically groundwater elevations, which are used to test the ability of a model to reproduce actual conditions within a groundwater flow system. For the calibration of a steady-state (time-invariant) model, the goal in selecting calibration targets is to define a set of water-level measurements that represent the average elevation of the water table or potentiometric surface at locations throughout the model domain.

Monitor wells and water-level elevations were chosen to calibrate the WRL flow model. This list of calibration targets is based on water level data collected on February 17, 1995. The calibration targets comprise a total of 81 monitor wells: 20 targets in the upper zone of the sand and gravel aquifer (layer 1); 11 targets in the lower zone of the sand and gravel aquifer (layer 2); 40 targets in the upper zone at the dolomite aquifer; 9 targets in the intermediate zone of the dolomite aquifer; and 3 targets in the deep zone at the dolomite aquifer.

# 4 GROUNDWATER FLOW MODEL CALIBRATION

Calibration of a groundwater flow model refers to the process of adjusting model parameters to obtain a reasonable match between observed and simulated water levels. In general, model calibration is an iterative procedure that involves variation of hydraulic properties or boundary conditions to achieve the best match between observed and simulated water levels. During model calibration, site-specific data and pumping tests were used as the primary constraints for the calibrated values of hydraulic conductivity based on the greater reliability of this data.

## 4.1 CALIBRATION PROCEDURE

For best calibration results, calibration of a model should rely on discrete measurements to produce answers free of contouring interpretations and artifacts. In the calibration of a groundwater flow model, use of point data eliminates the potential for interpretive bias that may result from attempting to match a contoured potentiometric surface (Konikow, 1978; Anderson and Woessner, 1992). In calibrating the groundwater flow model for the WRL site, 81 water-level calibration targets measured in monitor wells distributed in the unconsolidated and bedrock aquifer system were used (Table 4-1).

As a further goal for the calibration of a model, GeoTrans relies on the principle of parameter parsimony, which seeks to achieve an adequate calibration of a model through the use of the fewest number of model parameters was relied on. It should be noted that the use of greater numbers of model parameters during model calibration creates a situation in which many combinations of model parameter values produce equivalent calibration results. In this case, the model calibration parameters are called nonunique. Following the principal of parameter parsimony reduces the degree of nonuniqueness and results in more reliable calibrated parameter values. The information gathered for the conceptual model guides any decision to add model parameters (e.g., zones of hydraulic conductivity) to the model during

Table 4-1. Observed Versus Simulated Groundwater Elevations for the Calibrated Model in the Vicinity of the Winnebago Reclamation Landfill.

| Well | Observed Water Level (ft msl) | Simulated Water Level (ft msl) | Residual[1] (ft) |
|---|---|---|---|
| B1 | 729.070 | 729.473 | -0.403 |
| B10 | 712.590 | 717.280 | -4.69 |
| B10A | 713.440 | 717.280 | -3.84 |
| B11 | 719.390 | 718.562 | 0.828 |
| B11A | 718.890 | 718.562 | 0.328 |
| B12 | 720.020 | 717.841 | 2.18 |
| B13 | 713.660 | 713.348 | 0.312 |
| B14 | 711.300 | 711.725 | -0.425 |
| B14A | 710.900 | 711.723 | -0.823 |
| B15 | 707.550 | 707.496 | 0.053 |
| B15P | 707.820 | 710.125 | -2.30 |
| B16 | 722.920 | 723.678 | -0.758 |
| B2 | 728.900 | 727.965 | 0.935 |
| B4 | 730.880 | 731.744 | -0.864 |
| B6D | 724.810 | 723.879 | 0.931 |
| B6S | 726.470 | 726.947 | -0.47 7 |
| B7 | 728.750 | 729.644 | -0.894 |
| B8 | 721.070 | 719.512 | 1.56 |
| B9 | 721.730 | 721.487 | 0.24 |
| E3 | 709.940 | 710.429 | -0.489 |
| G104 | 707.170 | 707.142 | 0.032 |
| G105R | 719.100 | 717.856 | 1.24 |
| G108 | 715.090 | 717.657 | -2.57 |
| G109 | 720.990 | 717.861 | 3.13 |
| G110 | 715.080 | 714.640 | 0.44 |

Table 4-1. Observed Versus Simulated Groundwater Elevations for the Calibrated Model in the Vicinity of the Winnebago Reclamation Landfill (Continued).

| Well | Observed Water Level (ft msl) | Simulated Water Level (ft msl) | Residual[1] (ft) |
|---|---|---|---|
| G111 | 716.980 | 717.371 | -0.391 |
| G111A | 716.980 | 717.342 | -0.362 |
| G112 | 720.390 | 717.874 | 2.52 |
| G113 | 718.670 | 717.082 | 1.59 |
| G113A | 718.440 | 717.098 | 1.34 |
| G114 | 718.460 | 715.901 | 2.56 |
| G115 | 713.180 | 712.912 | 0.268 |
| G116 | 706.250 | 706.919 | -0.669 |
| G116A | 706.510 | 706.924 | -0.414 |
| G116D | 706.580 | 707.648 | -1.07 |
| G117 | 707.080 | 706.994 | 0.086 |
| G118A | 707.310 | 707.191 | 0.119 |
| G118R | 707.310 | 707.192 | 0.118 |
| R119 | 706.910 | 707.079 | -0.169 |
| G119A | 706.660 | 707.083 | -0.423 |
| G122 | 719.570 | 717.859 | 1.71 |
| G123 | 712.200 | 710.934 | 1.27 |
| G124 | 711.940 | 711.678 | 0.262 |
| G127 | 711.190 | 711.447 | -0.257 |
| G128 | 710.830 | 711.156 | -0.326 |
| G130 | 708.090 | 707.430 | 0.660 |
| G130A | 708.130 | 708.392 | -0.262 |
| G131 | 708.460 | 708.601 | -0.141 |
| G131A | 710.250 | 709.778 | 0.472 |
| G132 | 706.950 | 708.072 | -1.12 |

Table 4-1. Observed Versus Simulated Groundwater Elevations for the Calibrated Model in the Vicinity of the Winnebago Reclamation Landfill (Continued).

| Well | Observed Water Level (ft msl) | Simulated Water Level (ft msl) | Residual[1] (ft) |
|---|---|---|---|
| G26D | 711.410 | 711.695 | -0.285 |
| MW102 | 730.210 | 732.146 | -1.94 |
| MW103 | 730.920 | 729.205 | 1.72 |
| MW106 | 706.790 | 707.052 | -0.262 |
| MW201B | 723.550 | 724.244 | -0.694 |
| P3R | 706.780 | 707.153 | -0.373 |
| P4R | 706.900 | 707.161 | -0.261 |
| P6 | 713.210 | 713.996 | -0.786 |
| P8 | 726.530 | 726.472 | 0.058 |
| P9 | 726.570 | 726.472 | 0.098 |
| STI-1D | 730.760 | 731.405 | -0.645 |
| STI-1I | 730.490 | 731.835 | -1.35 |
| STI-1S | 730.950 | 732.423 | -1.47 |
| STI-2D | 722.640 | 721.418 | 1.22 |
| STI-2S | 722.070 | 721.857 | 0.213 |
| STI-4D | 720.680 | 722.854 | -2.17 |
| STI-4I | 721.000 | 723.153 | -2.15 |
| STI-4S | 722.380 | 723.495 | -1.11 |
| STI-5D | 720.520 | 720.491 | 0.029 |
| STI-5I | 721.560 | 722.006 | -0.446 |
| B16A | 722.970 | 721.644 | 1.33 |
| B5 | 726.000 | 725.012 | 0.988 |
| E2A | 714.570 | 713.285 | 1.28 |
| G109A | 719.880 | 717.483 | 2.40 |
| G26 | 711.400 | 711.696 | -0.296 |

Table 4-1. Observed Versus Simulated Groundwater Elevations for the Calibrated Model in the Vicinity of the Winnebago Reclamation Landfill (Continued).

| Well | Observed Water Level (ft msl) | Simulated Water Level (ft msl) | Residual[1] (ft) |
|---|---|---|---|
| MW105 | 726.490 | 726.947 | -0.457 |
| MW201A | 719.920 | 722.878 | -2.96 |
| STI-2I | 722.500 | 721.418 | 1.08 |
| G120B | 721.040 | 720.457 | 0.583 |
| G107 | 708.380 | 707.709 | 0.671 |
| P-1 | 706.790 | 707.060 | -0.270 |

[1]Residual = Observed - Simulated Water Level.

the calibration process. Therefore, in the absence of hydrogeologic evidence, the simpler model is preferred.

An automatic parameter estimation procedure was applied to calibrate the groundwater flow model. Starting with a set of initial estimates for the model parameters, the procedure systematically updates the parameter estimates to minimize the difference between simulated and observed water levels at a set of calibration targets. Compared to trial and error procedures for model calibration, automatic parameter estimation can greatly reduce the time required for model calibration and generally provide a better overall calibration. The general algorithm applied in conjunction with the MODFLOW code is known as the Gauss-Newton method and is described in greater detail in Hill (1992).

The primary criterion for evaluating the calibration of a groundwater flow model is the difference between simulated and observed water levels at a set of calibration targets. A residual or model error, $e_i$, is defined as the difference between the observed and simulated hydraulic head measured at target location:

$$e_i = h_i - \hat{h}_i \tag{4-1}$$

where $h_i$ is the measured value of hydraulic head and $\hat{h}_i$ is the simulated value at the I target location. A residual with a negative sign indicates over-prediction by the model (i.e., the simulated head is higher than the measured value). Conversely, a positive residual indicates under-prediction.

The automatic parameter estimation procedure seeks to minimize an objective function defined by the residual sum of squares (RSS):

$$RSS = \sum_{i=1}^{n} \left(h_i - \hat{h}_i\right)^2 \tag{4-2}$$

where n is the total number of calibration targets. The RSS is the primary measure of model fit. The residual standard deviation (RSTD), which normalizes the RSS by the number of calibration targets and number of estimated parameters (p), is defined as follows:

$$\mathrm{RSTD} = \sqrt{\frac{\mathrm{RSS}}{n - p}} \tag{4-3}$$

The RSTD is useful for comparing model calibrations with different numbers of calibration targets and estimated parameters. Another calibration measure is the mean of all residuals (ħ):

$$\bar{e} = \frac{1}{n} \sum_{i=1}^{n} e_i \tag{4-4}$$

A mean residual significantly different from zero indicates model bias. The Gauss-Newton parameter estimation procedure produces a near zero mean residual at the minimum RSS.

## 4.2 CALIBRATION RESULTS

The groundwater flow model calibration required approximately 75 individual computer simulations during the application of the automatic parameter estimation code. Using a wide range (zero to 18 in/yr) of constant areal recharge rates, vertical and horizontal hydraulic conductivity values were estimated using the automatic parameter estimation technique. Only moderately high values of constant areal recharge rate (13 to 18 in/yr) produced the observed distribution of water levels with reasonable estimated values of hydraulic conductivity in both the unconsolidated and bedrock aquifers. Once this range of areal recharge rate was determined, parameter estimation was continued to provide more refined estimates of each model parameter value during calibration.

Using the 81 water-level targets selected for the calibration of the WRL groundwater flow model, the calibration of the model was evaluated through the analysis of: 1) simulated hydraulic head distributions in the model; 2) residual statistics; and 3) estimated hydraulic parameters.

### 4.2.1 SIMULATED HYDRAULIC HEAD DISTRIBUTIONS

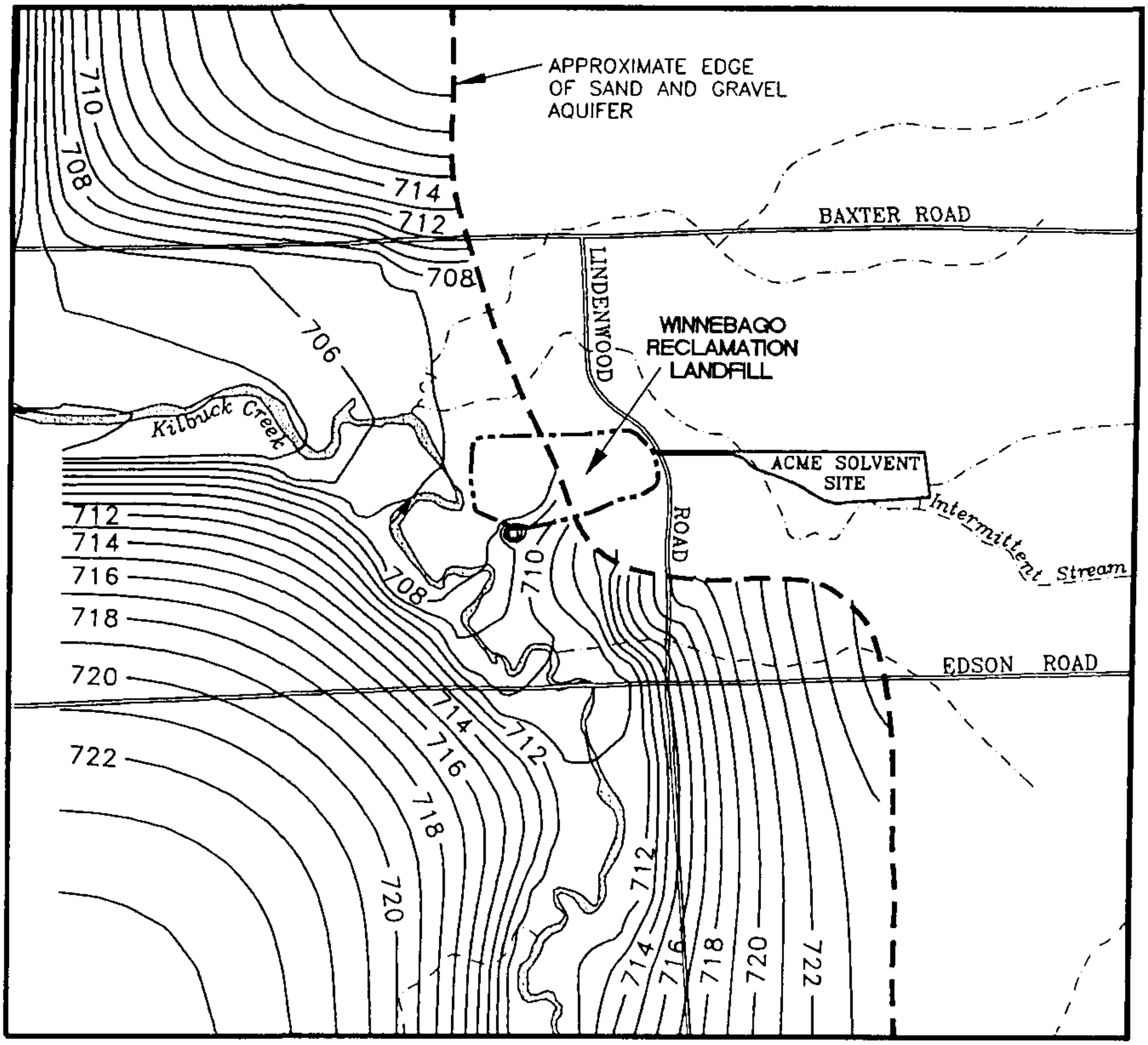
As a part of evaluating the calibration of the numerical model, simulated potentiometric surface maps were prepared for each of the aquifers to show regional groundwater flow conditions over the entire model domain (Figures 4-1 through 4-5). For a more detailed assessment, we also developed simulated potentiometric surface maps for a local area encompassing the WRL site (Figures 4-6 through 4-10).

The simulated regional water levels in the sand and gravel aquifer are shown in Figures 4-1 and 4-2. It is apparent that groundwater flow is generally toward Kilbuck Creek in the upper part of the sand and gravel aquifer. In the lower part of the sand and gravel aquifer, groundwater also discharges to Kilbuck Creek via upflow to the upper zone.

Figures 4-3 through 4-5 show the simulated regional water levels in the dolomite bedrock aquifer. Groundwater flow in this aquifer is primarily to the west. A large amount of groundwater flows upward and discharging to the higher permeability sand and gravel aquifer. In the deep zone, however, groundwater flows primarily horizontally toward the west.

Figure 4-6 shows the simulated local water levels and model residuals in the upper part of the sand and gravel aquifer. In this aquifer, shallow horizontal groundwater flow is generally toward Kilbuck Creek. It is apparent that groundwater mounding occurs south of the landfill near G115. This mounding is formed due to the presence of lower permeability silts and clay in the upper zone of the sand and gravel aquifer. The contours and model residuals indicate an excellent match with observed flow directions and water-level elevations (see Figure 2-16).

The simulated local water levels and residuals for the lower zone at the sand and gravel aquifer are shown in Figure 4-7. Simulated groundwater flow directions and water-level elevations exhibit a good match with the measured flow directions and water-level




LEGEND

-720- Water-Level Elevation (ft, msl)

-N-

0 2000'
SCALE IN FEET

TITLE: SIMULATED REGIONAL STEADY-STATE WATER LEVELS IN MODEL LAYER 1 (UPPER ZONE OF THE SAND AND GRAVEL AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
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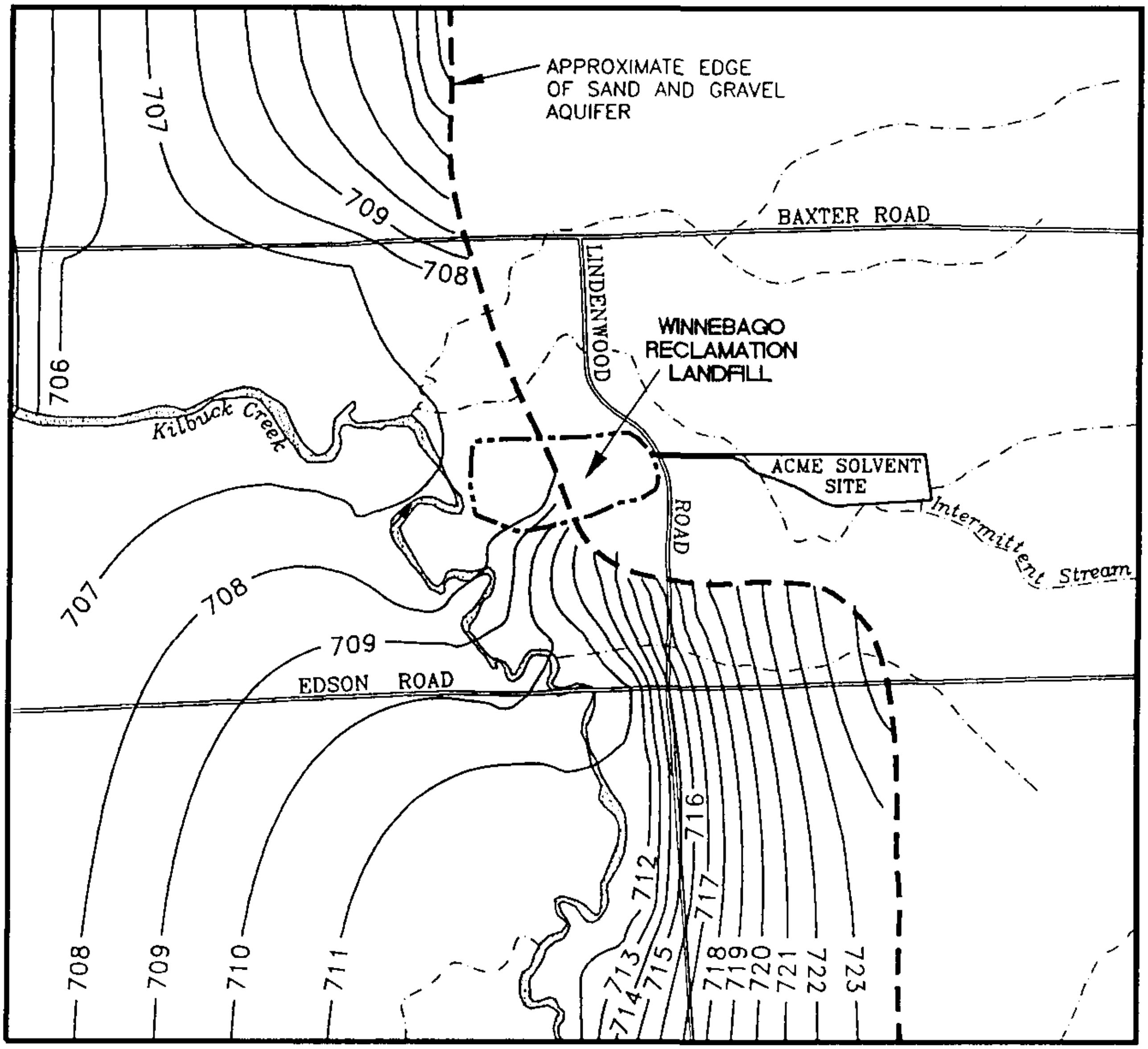
| DATE: | 6-29-95 | |




LEGEND

-720- Water-Level Elevation (ft, msl)

-N-

0 2000'

SCALE IN FEET

| | |
|---|---|
| TITLE: | SIMULATED REGIONAL STEADY-STATE WATER LEVELS IN MODEL LAYER 2 (LOWER ZONE OF THE SAND AND GRAVEL AQUIFER). |
| LOCATION: | Winnebago Reclamation Services, Rockford, IL. |

GeoTrans, inc. GROUNDWATER SPECIALISTS

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|---|---|---|
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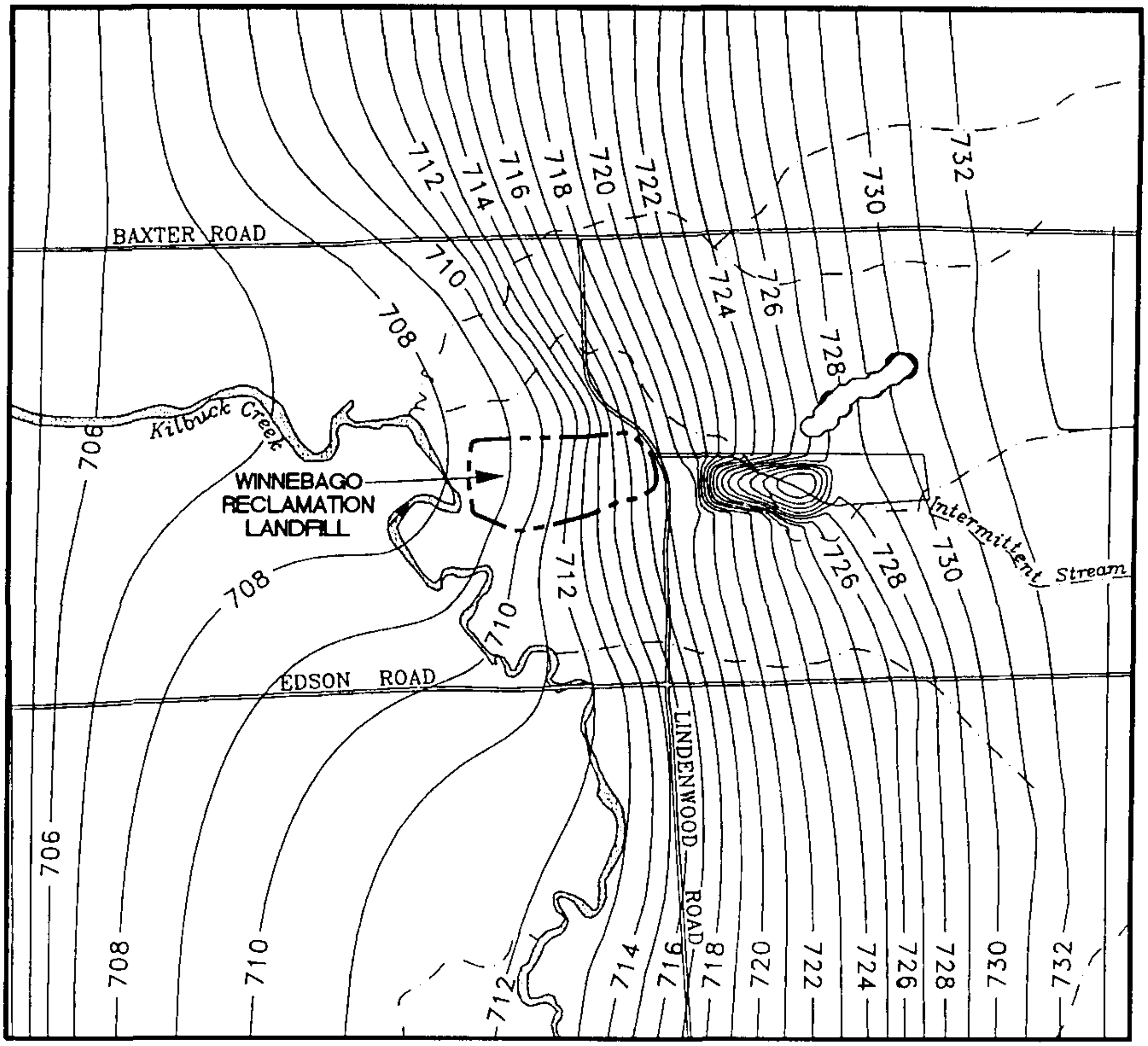
| DATE: | 6-29-95 | |




LEGEND

-720- Water-Level Elevation (ft, msl)

TITLE: SIMULATED REGIONAL STEADY-STATE WATER LEVELS IN MODEL LAYER 3 (UPPER ZONE OF DOLOMITE BEDROCK AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

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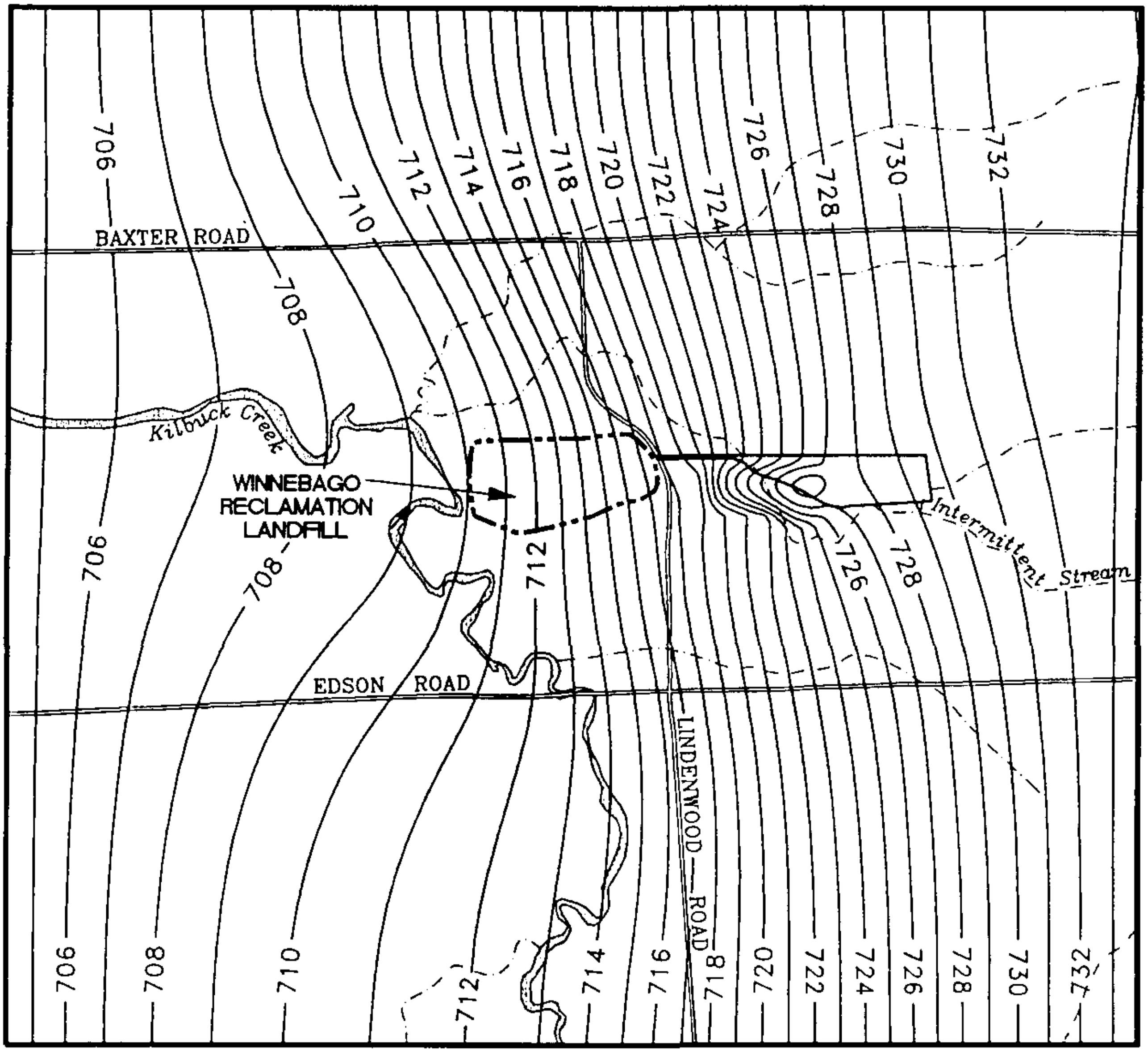
| DATE: | 6-29-95 |

FIGURE: 4-3




LEGEND

-720- Water-Level Elevation (ft, msl)

-N-

0 2000'

SCALE IN FEET

TITLE: SIMULATED REGIONAL STEADY-STATE WATER LEVELS IN MODEL LAYER 4 (INTERMEDIATE ZONE OF DOLOMITE BEDROCK AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

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GROUNDWATER SPECIALISTS

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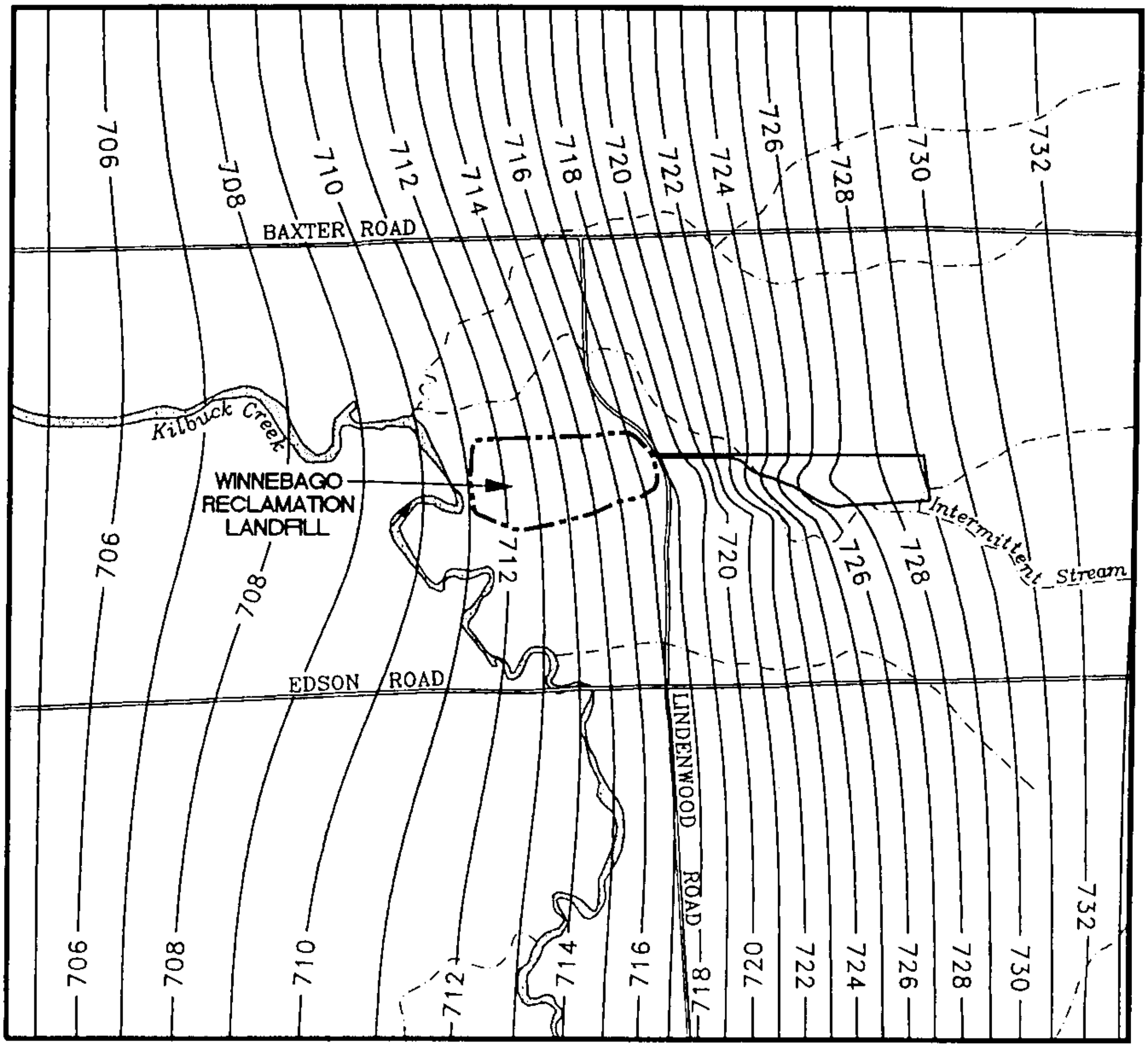
|---|---|---|
| CHECKED: | D.B. | FIGURE: 4-4 |
| DRAFTED: | C.S. | |
| FILE: | 7735FM4 | |
| DATE: | 6-29-95 | |




LEGEND

–720– Water–Level Elevation (ft, msl)

-N-

0 2000'

SCALE IN FEET

TITLE: SIMULATED REGIONAL STEADY–STATE WATER LEVELS IN MODEL LAYER 5 (DEEP ZONE OF DOLOMITE BEDROCK AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

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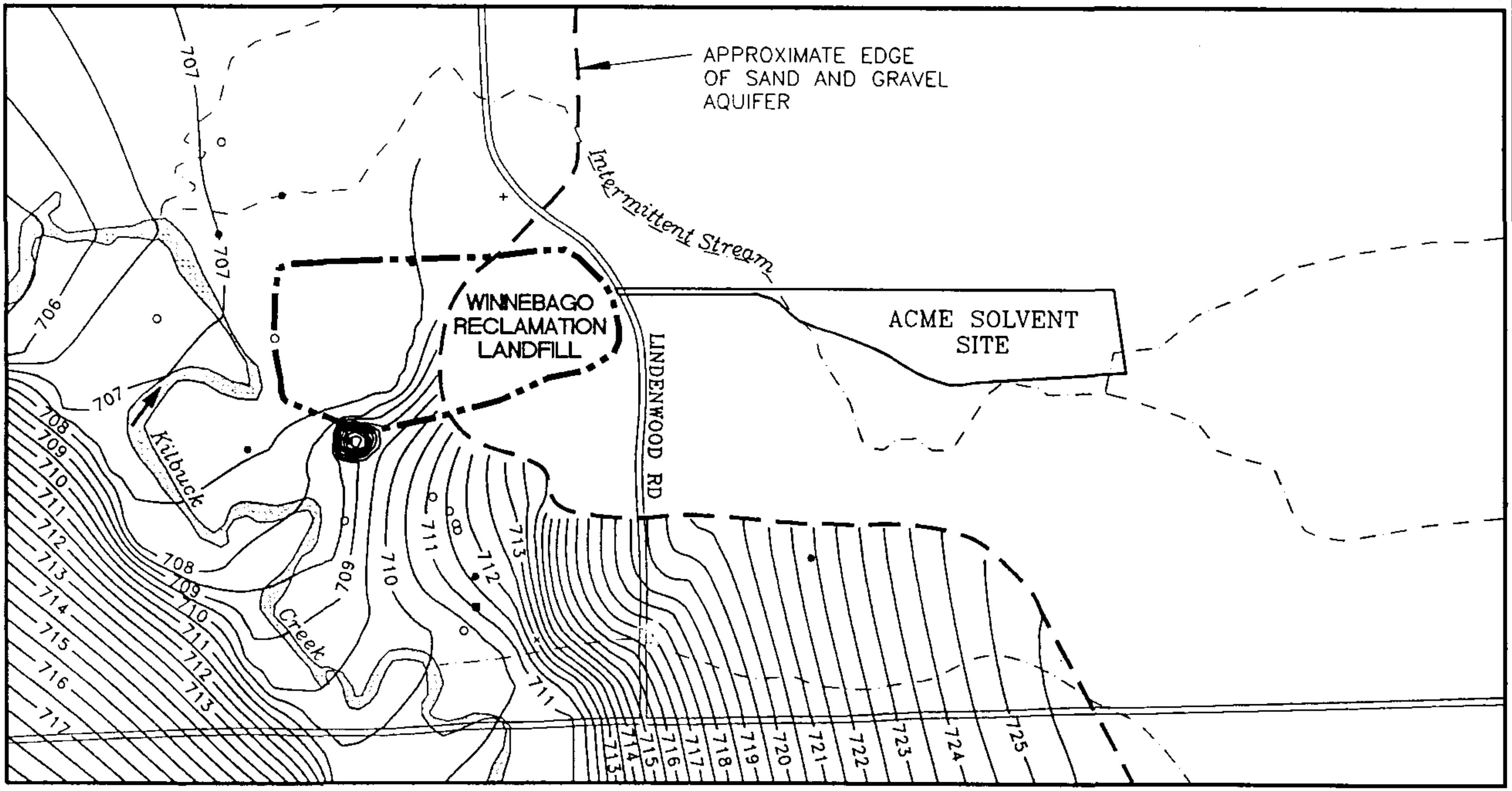


LEGEND

—720— Water-Level Elevation (ft, msl)

Residual at Target Location

| | |
|---|---|
| + < −3 Ft | × + −3 Ft |
| △ −3 to −2 Ft | ▲ 2 to 3 Ft |
| □ −2 to −1 Ft | ■ 1 to 2 Ft |
| ○ −1 to 0 Ft | ● 0 to 1 Ft |

-N-

0 1000'
SCALE IN FEET

TITLE: SIMULATED LOCAL STEADY-STATE WATER LEVELS IN MODEL LAYER 1 (UPPER ZONE OF SAND AND GRAVEL AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: 4-6 |
| DRAFTED: | C.S. | |
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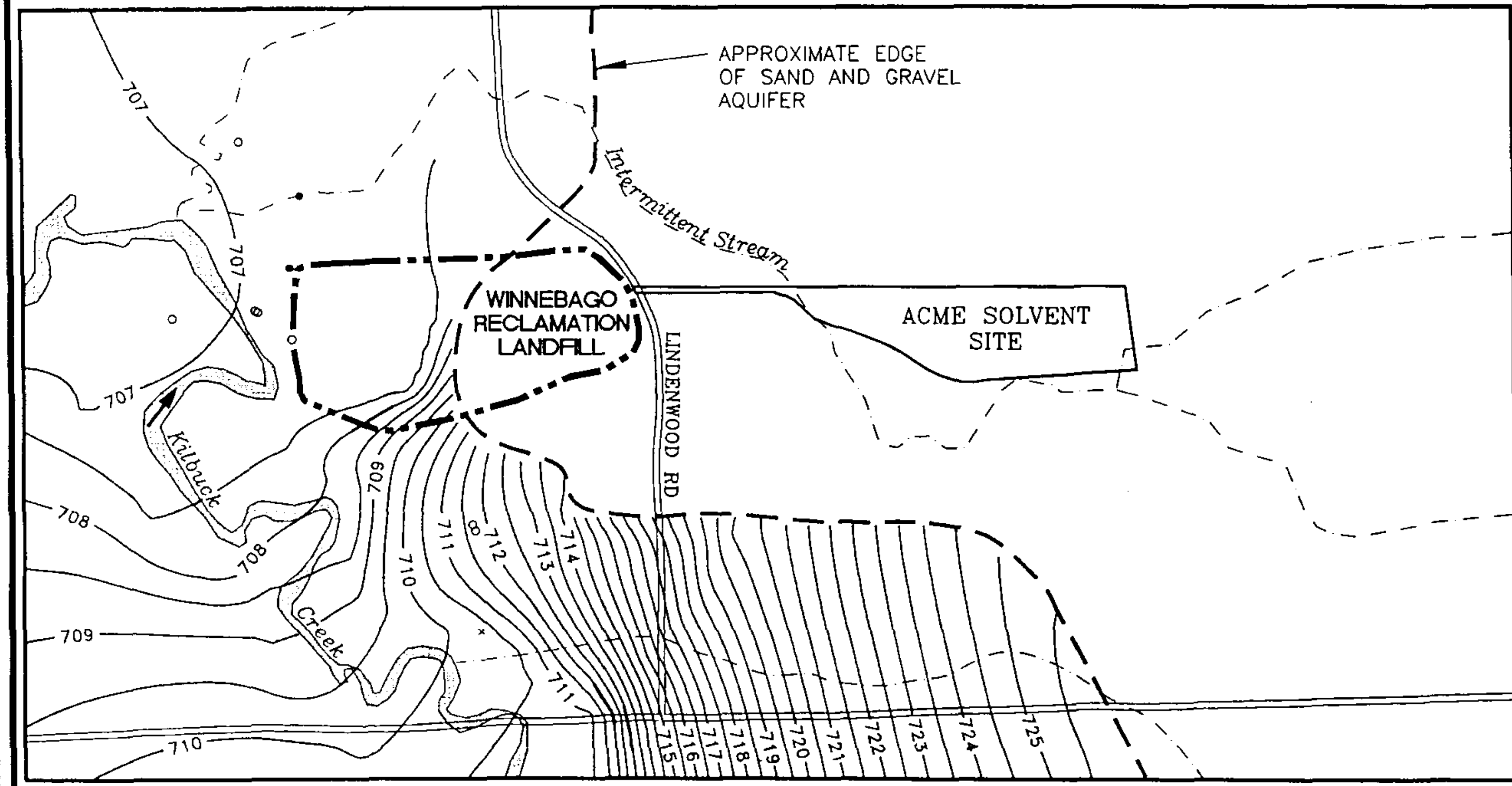
| DATE: | 6-29-95 | |




LEGEND

—720— Water-Level Elevation (ft, msl)

Residual at Target Location

| | | | |
|---|---|---|---|
| + | < −3 Ft | × | + −3 Ft |
| △ | −3 to −2 Ft | ▲ | 2 to 3 Ft |
| □ | −2 to −1 Ft | ■ | 1 to 2 Ft |
| ○ | −1 to 0 Ft | ● | 0 to 1 Ft |

-N-

0 1000'
SCALE IN FEET

TITLE: SIMULATED LOCAL STEADY-STATE WATER LEVELS IN MODEL LAYER 2 (UPPER ZONE OF SAND AND GRAVEL AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: 4-7 |
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| FILE: | 7735FM7 | |
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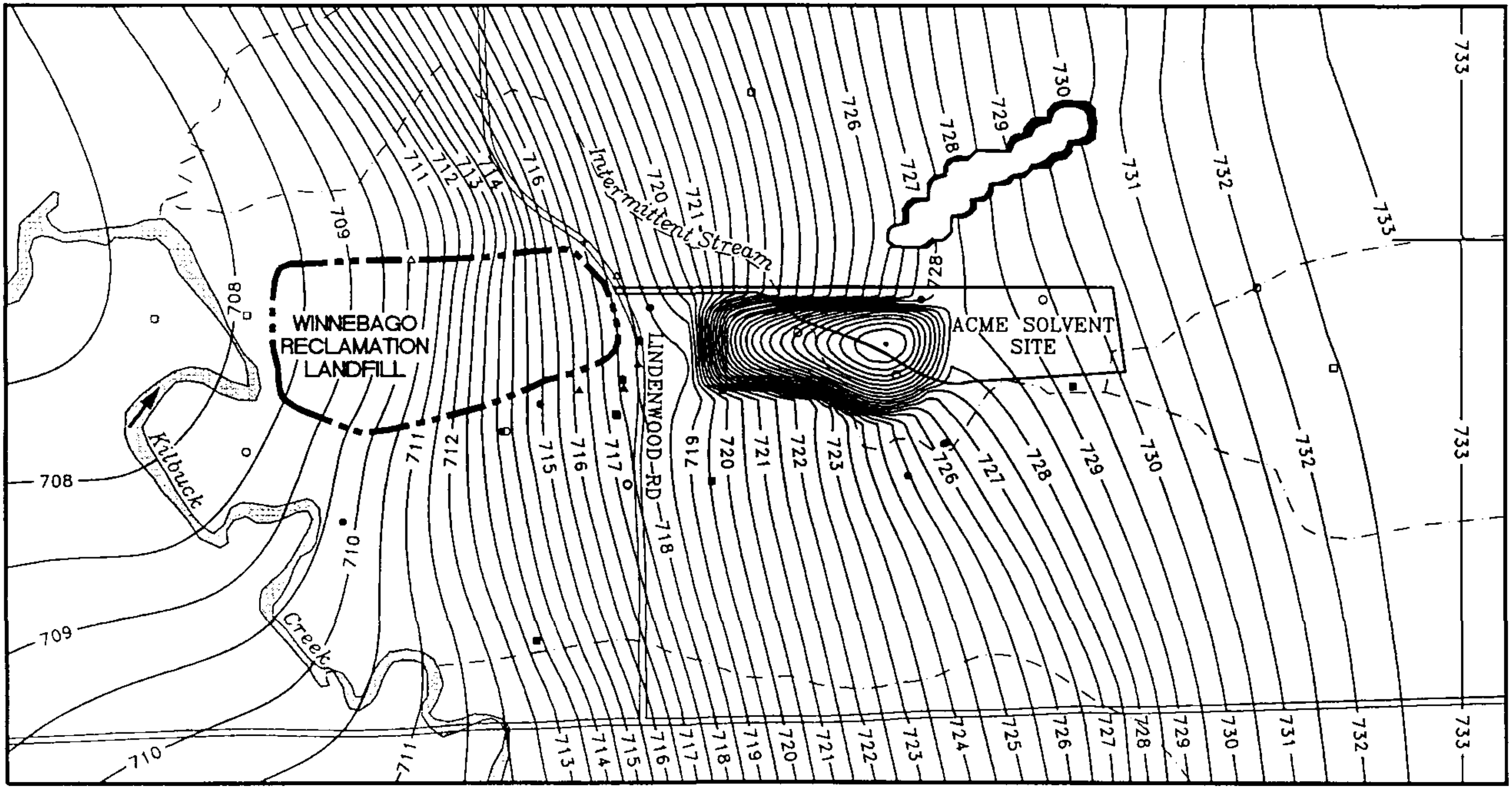



**LEGEND**

—720— Water–Level Elevation (ft, msl)

Residual at Target Location

| | | | |
|---|---|---|---|
| + | < −3 Ft | × | + −3 Ft |
| △ | −3 to −2 Ft | ▲ | 2 to 3 Ft |
| □ | −2 to −1 Ft | ■ | 1 to 2 Ft |
| ○ | −1 to 0 Ft | ● | 0 to 1 Ft |

-N-

0 1000'

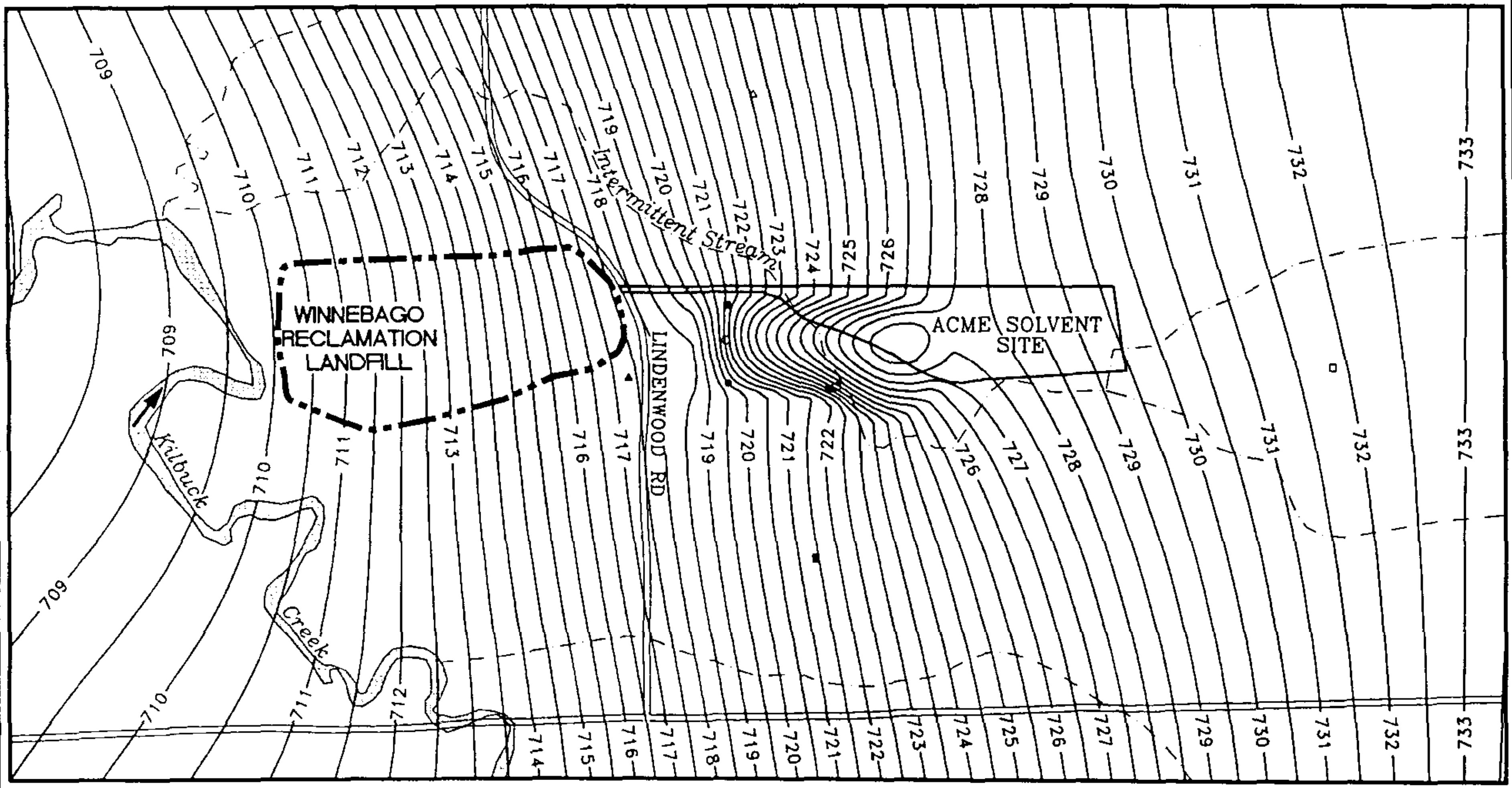
SCALE IN FEET

TITLE: SIMULATED LOCAL STEADY–STATE WATER LEVELS IN MODEL LAYER 3 (UPPER ZONE OF DOLOMITE AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: |
| DRAFTED: | C.S. | 4–8 |
| FILE: | 7735FMB | |
| DATE: | 6–29–95 | |




LEGEND

—720— Water-Level Elevation (ft, msl)

Residual at Target Location

| | | | |
|---|---|---|---|
| + | < −3 Ft | × | + −3 Ft |
| △ | −3 to −2 Ft | ▲ | 2 to 3 Ft |
| □ | −2 to −1 Ft | ■ | 1 to 2 Ft |
| ○ | −1 to 0 Ft | ● | 0 to 1 Ft |

N

0 1000'

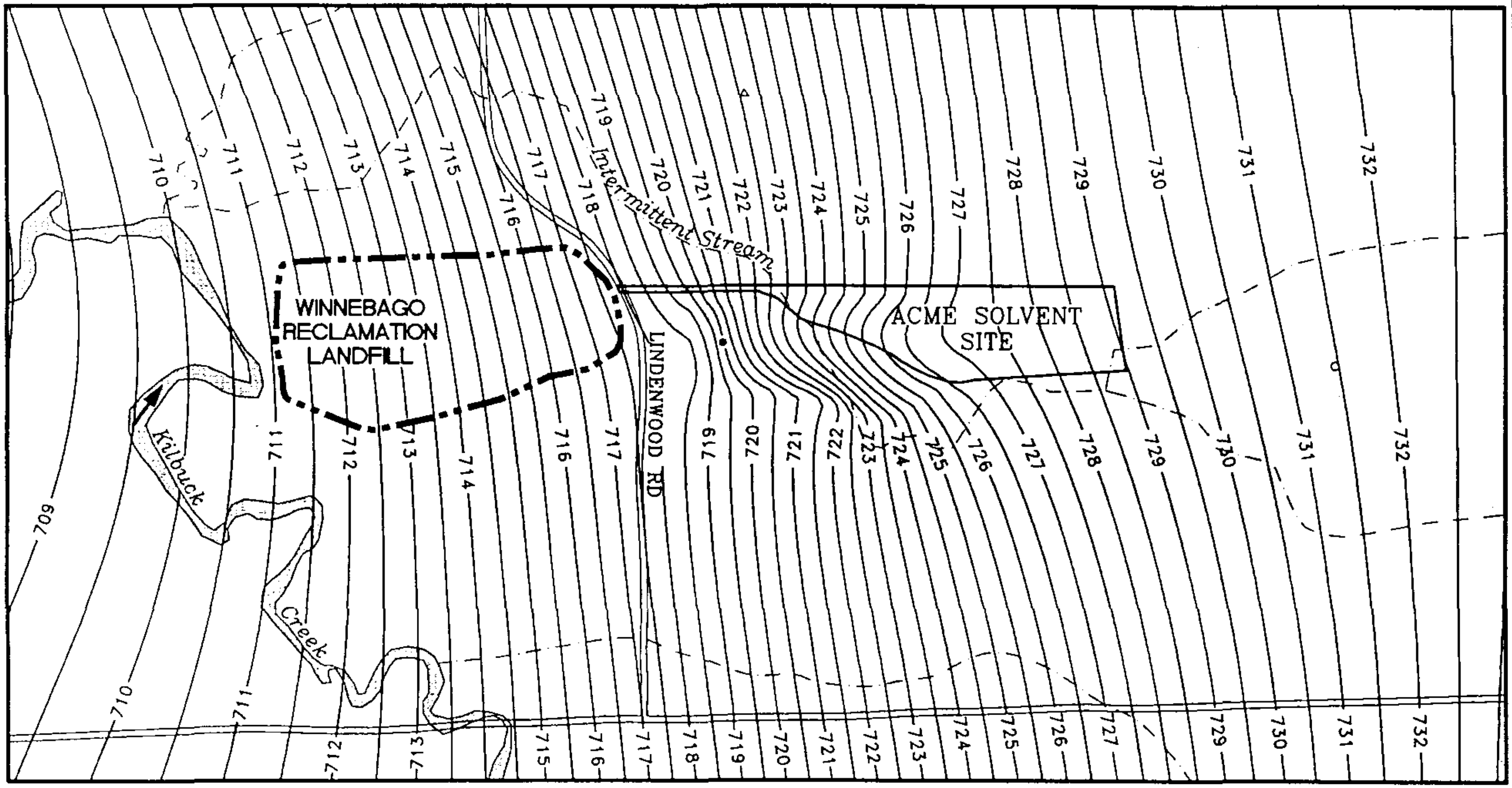
SCALE IN FEET

TITLE: SIMULATED LOCAL STEADY-STATE WATER LEVELS IN MODEL LAYER 4 (INTERMEDIATE ZONE OF DOLOMITE BEDROCK AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: 4-9 |
| DRAFTED: | C.S. | |
| FILE: | 7735FM9 | |
| DATE: | 6-29-95 | |




LEGEND

—720— Water-Level Elevation (ft, msl)

Residual at Target Location

| | |
|---|---|
| + < −3 Ft | × + −3 Ft |
| △ −3 to −2 Ft | ▲ 2 to 3 Ft |
| □ −2 to −1 Ft | ■ 1 to 2 Ft |
| ○ −1 to 0 Ft | ● 0 to 1 Ft |

-N-

0 1000'
SCALE IN FEET

TITLE: SIMULATED LOCAL STEADY-STATE WATER LEVELS IN MODEL LAYER 5 (DEEP ZONE OF DOLOMITE AQUIFER).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

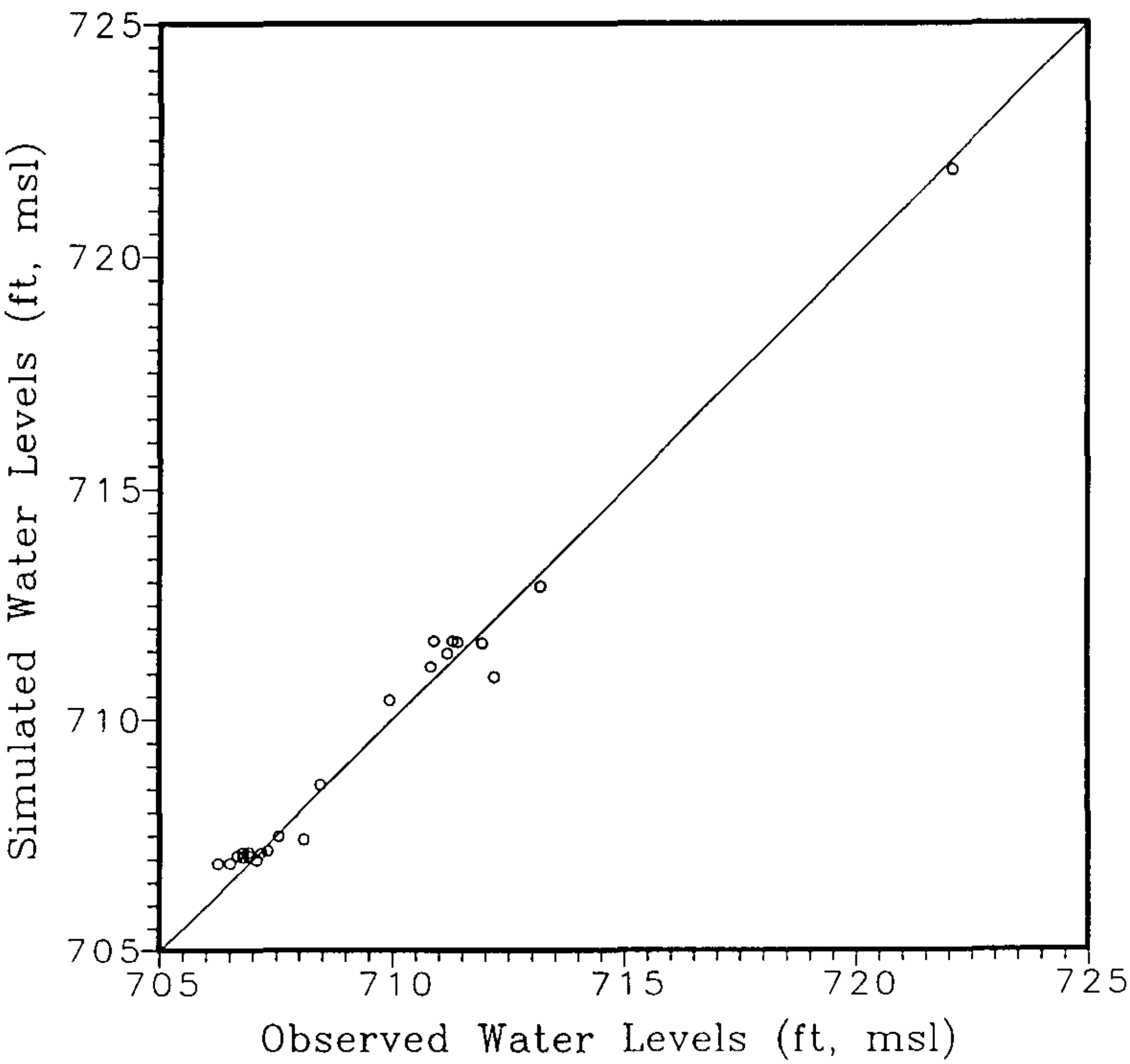
| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: |
| DRAFTED: | C.S. | 4-10 |
| FILE: | 7735FM10 | |
| DATE: | 6-29-95 | |

elevations (see Figure 2-17). The low model residual values also indicate the close match between simulated and measured water levels. These hydraulic head contours also show that groundwater flows beneath Kilbuck Creek and toward the northwest, as shown by particle tracking (see Section 5.2).

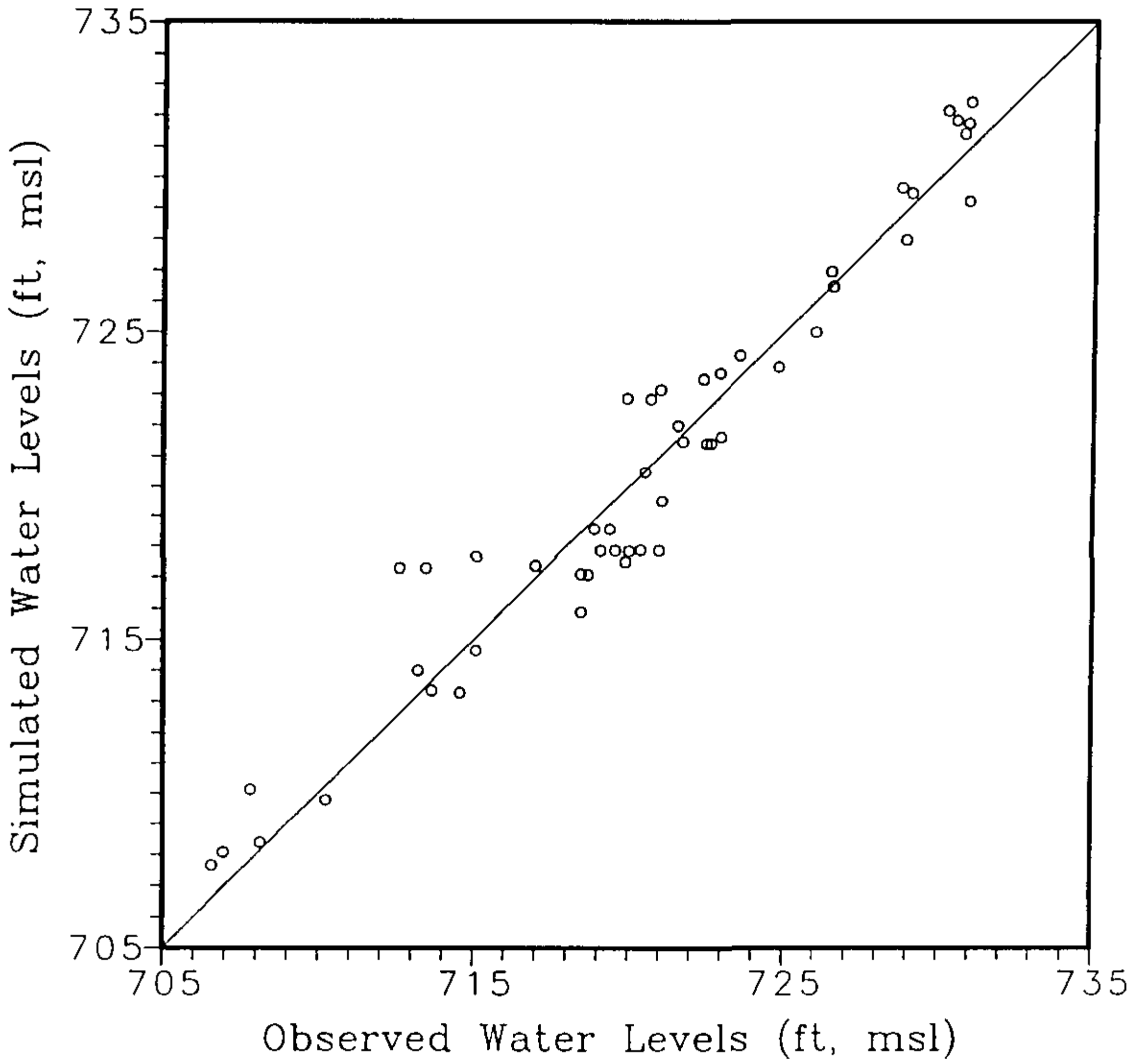
Figures 4-8, 4-9, and 4-10 show the simulated local water levels and residuals in the upper, intermediate, and lower zones of the dolomite bedrock aquifer. In this bedrock aquifer, groundwater flows generally to the west, which agrees well with the observed potentiometric surface map (see Figure 2-18). In addition, the low values of the model residuals show a good match between simulated and observed water-level elevations. The mounding of hydraulic head contours at the Acme site indicates the presence of a zone of lower hydraulic conductivity or possibly, an area of preferential recharge. A pumping test near B-6 indicates that a low permeability zone is present in this area ( HLA, 1990). Therefore, this area was represented by a low hydraulic conductivity zone in the model (see Section 4.2.3).

### 4.2.2 ANALYSIS OF RESIDUALS

The calibration of the groundwater flow model for the WRL site sought to minimize the residual sum of squares (equation 4-2) computed for the 81water-level calibration targets. Table 4-1 lists the simulated water elevations and model residuals for each of the calibration targets. The local maps of simulated hydraulic heads (Figure 4-6 through 4-10) show the spatial distribution of these residuals in each of the aquifers. The largest computed residual for the entire set of targets is 4.69 feet. Only ten residuals out of the 81 targets exceed two feet. Nearly 75 percent of the targets have residuals of 1.5 foot or less. Overall, the model shows a very good match to the measured water levels at the site. For each layer in the model, Figures 4-11 through 4-12 show graphically the agreement between observed and simulated water levels at the calibration targets for both the sand and gravel and bedrock aquifers, respectively.




| | | | | |
|---|---|---|---|---|
| TITLE: PLOT OF SIMULATED VERSUS OBSERVED WATER LEVELS IN THE SAND AND GRAVEL AQUIFER (MODEL LAYERS 1 AND 2). | | | | |
| LOCATION: Winnebago Reclamation Services, Rockford, IL. | | | | |
| GeoTrans, inc. GROUNDWATER SPECIALISTS | CHECKED: | D.B. | FIGURE: 4-11 | |
| | DRAFTED: | C.S. | | |
| | FILE: | 7735FM14 | | |
| | DATE: | 6-29-95 | | |




TITLE: PLOT OF SIMULATED VERSUS OBSERVED WATER LEVELS IN THE DOLOMITE BEDROCK AQUIFER (MODEL LAYERS 3, 4, AND 5 ).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
|---|---|---|
| CHECKED: | D.B. | FIGURE: 4-12 |
| DRAFTED: | C.S. | |
| FILE: | 7735FM15 | |
| DATE: | 6-29-95 | |

Table 4-2. Flow Model Calibration Statistics.

| Number of Residual | Observations Mean (ft) | Residual Standard Deviation (ft) | Residual Sum of Squares ($ft^2$) |
|---|---|---|---|
| 85 | -0.062 | 1.31 | 146.1 |

Residual statistics for the calibrated groundwater flow model also indicate good agreement between simulated and measured groundwater elevations. Table 4-2 shows the residual mean, residual standard deviation and residual sum of squares for the calibrated model. The mean is close to zero and the residual standard deviation is less than five percent of the range of simulated water-level elevations for the entire model domain. In comparison to residual statistics of groundwater flow models at other sites, these statistics show that a very high level of calibration standard has been achieved in this modeling effort.

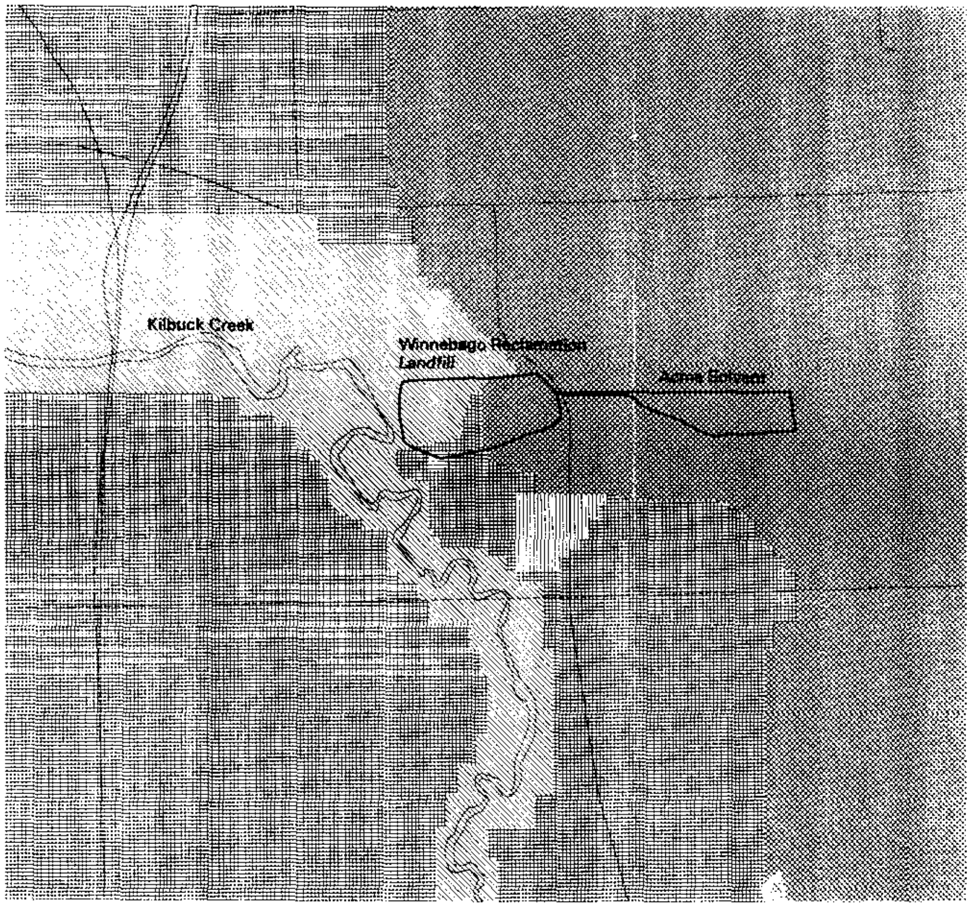
### 4.2.3 MODEL PARAMETER ZONATION

During the calibration of the model, three parameters (recharge, horizontal hydraulic conductivity of the aquifers and vertical hydraulic conductivity of the aquitards) were varied from their initial values to match measured and simulated water-level elevations at the calibration targets. The final calibrated values of these parameters are shown in Figures 4-13 through 4-16.

In order to match the different hydraulic gradients in the sand and gravel aquifer, two primary hydraulic conductivity zones were necessary. Figure 4-13 shows the hydraulic conductivity zonation and areal extent of the sand and gravel aquifer. Over most of the model domain, the calibrated horizontal and vertical hydraulic conductivity values in the sand and gravel aquifer were 40 and 20 ft/day, respectively. In the area along Kilbuck Creek. the calibrated horizontal and vertical hydraulic conductivity were 1500 and 150 ft/day, respectively. This zone of high hydraulic conductivity is in agreement with the observed hydraulic conductivity of 1500 ft/day based on a pumping test at RW-01 (GeoTrans, 1995a). The other local low hydraulic conductivity zone values are consistent with the presence of silts and clays in these areas.

Figure 4-14 shows the approximate areal extent of a low permeability aquitard within the sand and gravel aquifer. Near the WRL site, the areal extent of the clay aquitard was determined based on numerous soil borings in the area west of Kilbuck Creek. In the areas farther away from the WRL site, the presence of the clay aquitard is less certain and may be discontinuous. The calibrated vertical hydraulic conductivity at the aquitard was 0.00284

NORTH




Legend

Inactive Zone

$K_h$ = 0.10 ft/day
$K_v$ = 0.01 ft/day

$K_h$ = 3.00 ft/day
$K_v$ = 0.03 ft/day

$K_h$ = 40.0 ft/day
$K_v$ = 20.0 ft/day

$K_h$ = 1500.0 ft/day
$K_v$ = 150.0 ft/day

$K_h$ = Horizontal Hydraulic Conductivity
$K_v$ = Vertical Hydraulic Conductivity

0 2000

FEET

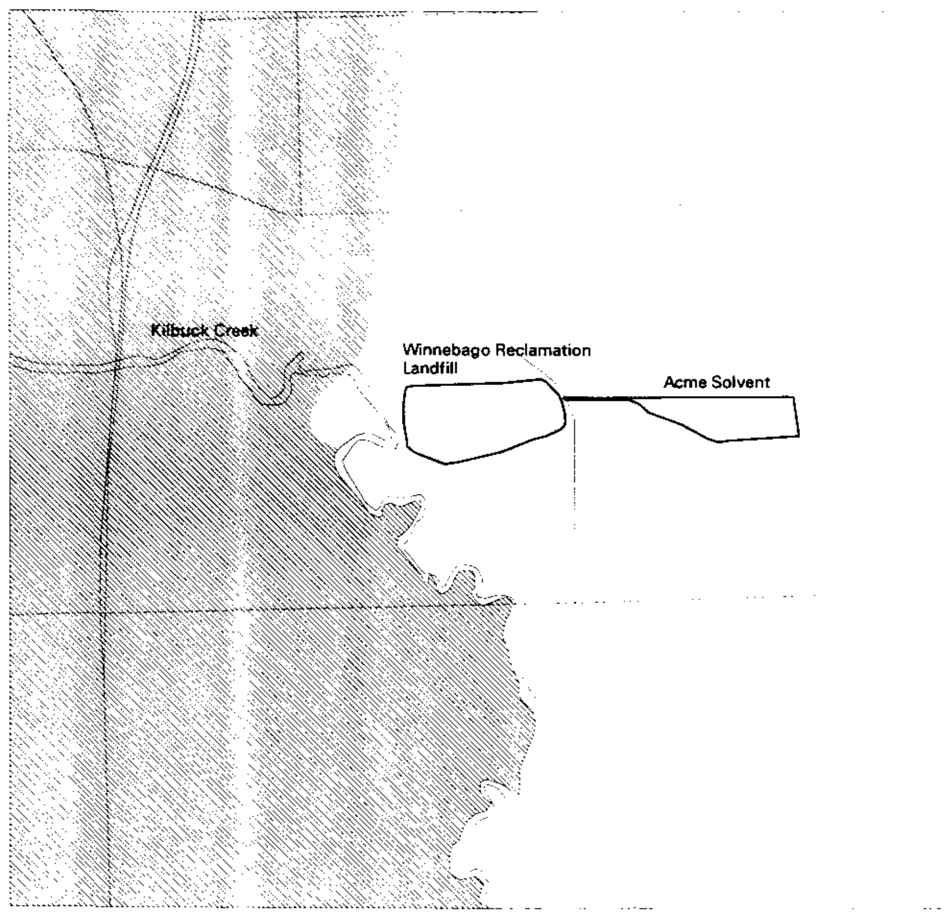
Hydraulic Conductivity Zonation in the Upper and Lower Zone of the Sand and Gravel Aquifer (Model Layers 1 and 2).

ID: fig4-13

DATE: 7/5/95

BY: mcb

FIGURE 4-13




NORTH

Legend

Aquitard
$K_v$ = 0.00284 ft/day

$K_v$ = Vertical Hydraulic Conductivity

0 2000

FEET

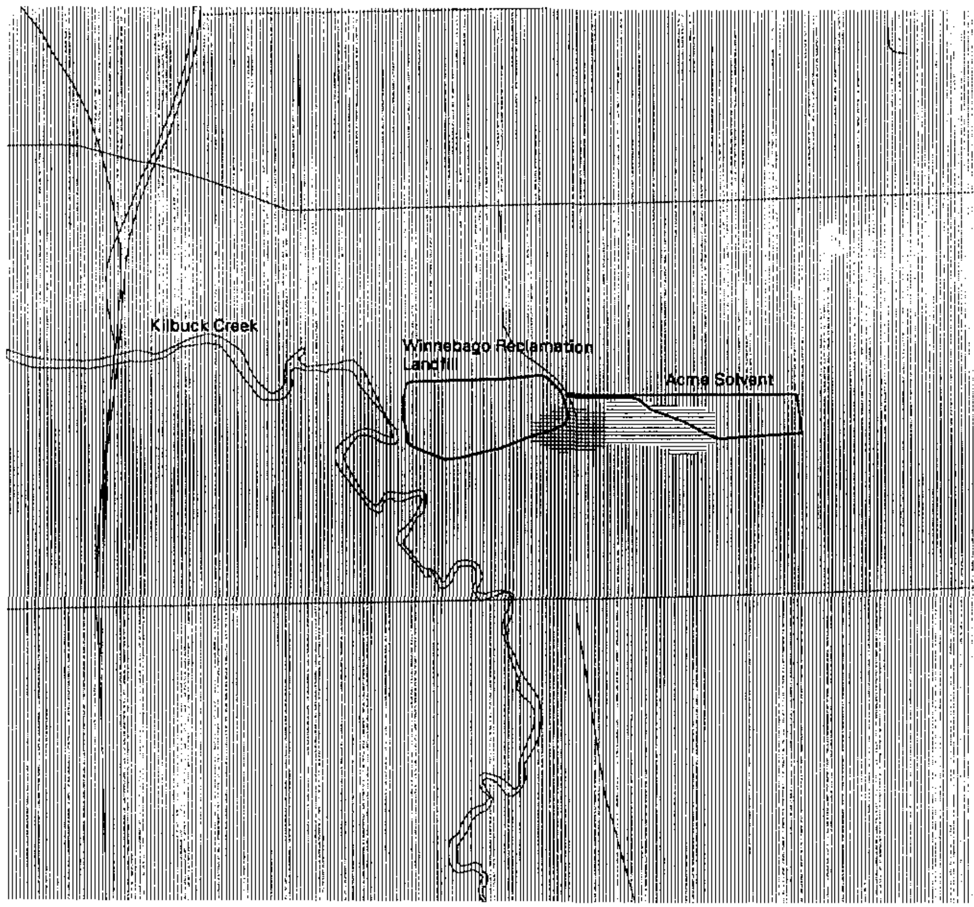
Areal Extent of Aquitard in the Sand and Gravel Aquifer.

ID: fig4-14

DATE: 7/5/95

BY: mcb

FIGURE 4-14



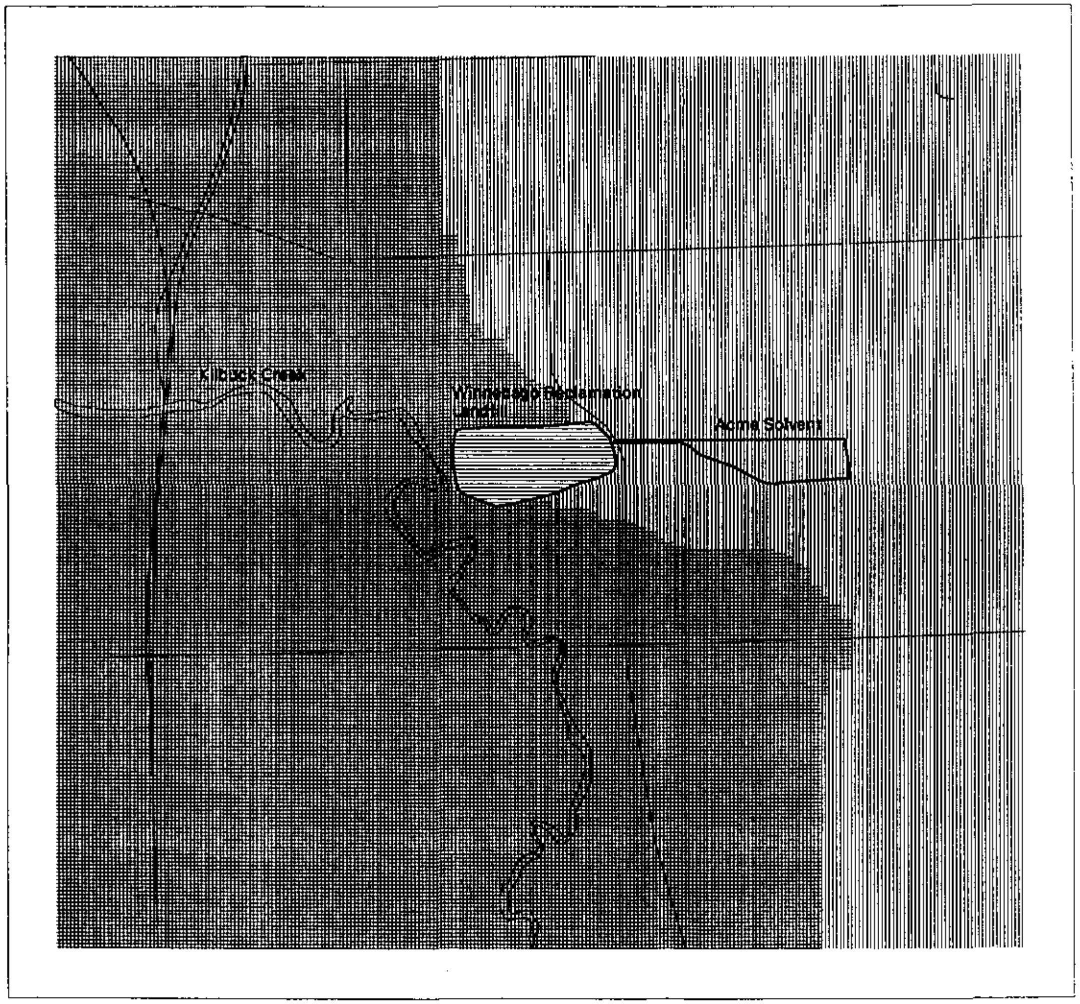

Hydraulic Conductivity Zonation in the Dolomite Bedrock Aquifer in (Model Layers 3, 4, and 5).

ID: fig4-15

DATE: 7/5/95

BY: mcb

FIGURE 4-15




NORTH

Legend

2.3 inches/year

13.8 inches/year

17.5 inches/year

0 2000

FEET

Precipitation Recharge rate Zonation in the Unconsolidated-Bedrock Aquifer System.

ID: fig4-16

DATE: 7/5/95

BY: mcb

FIGURE 4-16

ft/day, which is within the range of laboratory testing results (0.00037 to 0.0047 ft/day) from analysis of Shelby tube samples collected from the clay aquitard (GeoTrans, 1995a).

Figure 4-15 shows the hydraulic conductivity zonation within the dolomite bedrock aquifer. Over most of the model domain, the calibrated horizontal and vertical hydraulic conductivity values were 20 and 0.2 ft/day, respectively. A high hydraulic conductivity zone is present just east of the WRL based on observed gradients, soil logs, and constituent distributions, and is discussed in detail in the RI (Warzyn, 1991a). The calibrated horizontal and vertical hydraulic conductivity values in this zone were 100 and 10 ft/day, respectively. In the area just southeast of the Acme site, the calibrated horizontal and vertical hydraulic conductivities were 0.235 and 0.0235 ft/day, which are consistent with values determined from a pumping test in this area.

In the calibrated model, areal precipitation reaching the water table occurs within three distinct zones (Figure 4-16). In the area that the sand and gravel aquifer is present, the calibrated precipitation recharge rate was 17.5 in/yr. In areas where bedrock outcrops, the calibrated recharge rate was 13.8 in/yr. At the Winnebago Reclamation Landfill, the recharge rate is 2.3 in/yr based on HELP model simulations (Andrews Environmental Engineering, 1995).

### 4.3 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to examine the effects of uncertainties in each of the model calibration parameters. Table 4-3 shows the parameter, parameter value multiplier, and normalized residual sum of the squares. The response of the calibrated model to changes in zones of recharge, horizontal hydraulic conductivity of each aquifer, and vertical hydraulic conductivity was evaluated through a discrete sensitivity analysis. In this analysis, one parameter at a time was varied while all other parameters were held constant. Each calibrated parameter value was, in turn, multiplied by factors between at least 0.5 and 1.5 (a multiplier of 1.0 corresponds to the calibrated value of the parameter). The residual sum of squares (RSS) computed for each parameter perturbation was normalized by dividing by the RSS from the calibrated model. In other words, the calibrated model has a normalized RSS of 1.0,

Table 4-3. Summary of Sensitivity Analysis.

| Parameter | Multiplier | Normalized Sum of Squares |
|---|---|---|
| Precipitation Recharge Rate in unconsolidated sediment outcrop area | 0.5 | 1.69 |
| | 1.5 | 1.51 |
| Precipitation Recharge Rate in bedrock outcrop area | 0.5 | 1.00 |
| | 1.5 | 1.00 |
| Precipitation Recharge Rate at Winnebago Reclamation Landfill | 0.5 | 2.47 |
| | 1.5 | 2.92 |
| Hydraulic Conductivity in unconsolidated sediments | 0.5 | 1.17 |
| | 1.5 | 1.14 |
| Hydraulic Conductivity in dolomite bedrock | 0.5 | 2.26 |
| | 1.5 | 1.05 |
| Hydraulic Conductivity in clayey zone south of landfill | 0.5 | 1.00 |
| | 1.5 | 1.00 |
| Hydraulic Conductivity in low permeability bedrock zone east of WRL | 0.5 | 1.54 |
| | 1.5 | 0.988 |
| Hydraulic Conductivity in high permeability zone of unconsolidated sediments | 0.5 | 1.04 |
| | 1.5 | 1.02 |
| Hydraulic Conductivity in high permeability zone of dolomite bedrock | 0.5 | 1.02 |
| | 1.5 | 0.99 |
| Hydraulic Conductivity of local clay near monitor well G115 | 0.5 | 1.01 |
| | 1.5 | 1.01 |
| Vertical Hydraulic Conductivity in unconsolidated sediments | 0.5 | 1.00 |
| | 1.5 | 1.00 |
| Vertical Hydraulic Conductivity of clay aquitard located west of Kilbuck Creek | 0.5 | 1.00 |
| | 1.5 | 1.00 |
| Vertical Hydraulic Conductivity of dolomite bedrock | 0.5 | 1.32 |
| | 1.5 | 1.07 |

Table 4-3. Summary of Sensitivity Analysis (Continued).

| Parameter | Multiplier | Normalized Sum of Squares |
|---|---|---|
| Vertical Hydraulic Conductivity in clayey zone south of landfill | 0.5 | 1.00 |
| | 1.5 | 1.00 |
| Vertical Hydraulic Conductivity of low permeability bedrock zone east of WRL | 0.5 | 1.10 |
| | 1.5 | 1.00 |
| Vertical Hydraulic Conductivity of high permeability zone of unconsolidated sediments | 0.5 | 1.00 |
| | 1.5 | 1.00 |
| Vertical Hydraulic Conductivity of local clay near G115 | 0.5 | 1.00 |
| | 1.5 | 1.00 |
| Vertical Hydraulic Conductivity in high permeability bedrock zone | 0.5 | 1.00 |
| | 1.5 | 1.00 |

Note:
A multiplier of 0.5 and 1.5 are 50 percent parameter variations.

and a simulation that had twice its value would have a normalized RSS of 2.0. No significant improvement was achieved in the model calibration by these parameter changes.

The most sensitive model parameters were the areal precipitation recharge rate in the unconsolidated sediments, and the horizontal hydraulic conductivity of the bedrock aquifer. The higher degree of sensitivity of the model calibration to changes in recharge rate was expected because this parameter determines the amount of water entering these aquifers. The horizontal hydraulic conductivity of the dolomite bedrock aquifer is also sensitive because it affects both the amount of mounding due to recharge and also the amount on inflow at the upgradient model boundary. An additional model parameter which exhibited sensitivity was the low hydraulic conductivity zone in bedrock located east of the WRL site. The vertical hydraulic conductivity of typical dolomite bedrock also exhibited a lesser degree of sensitivity.

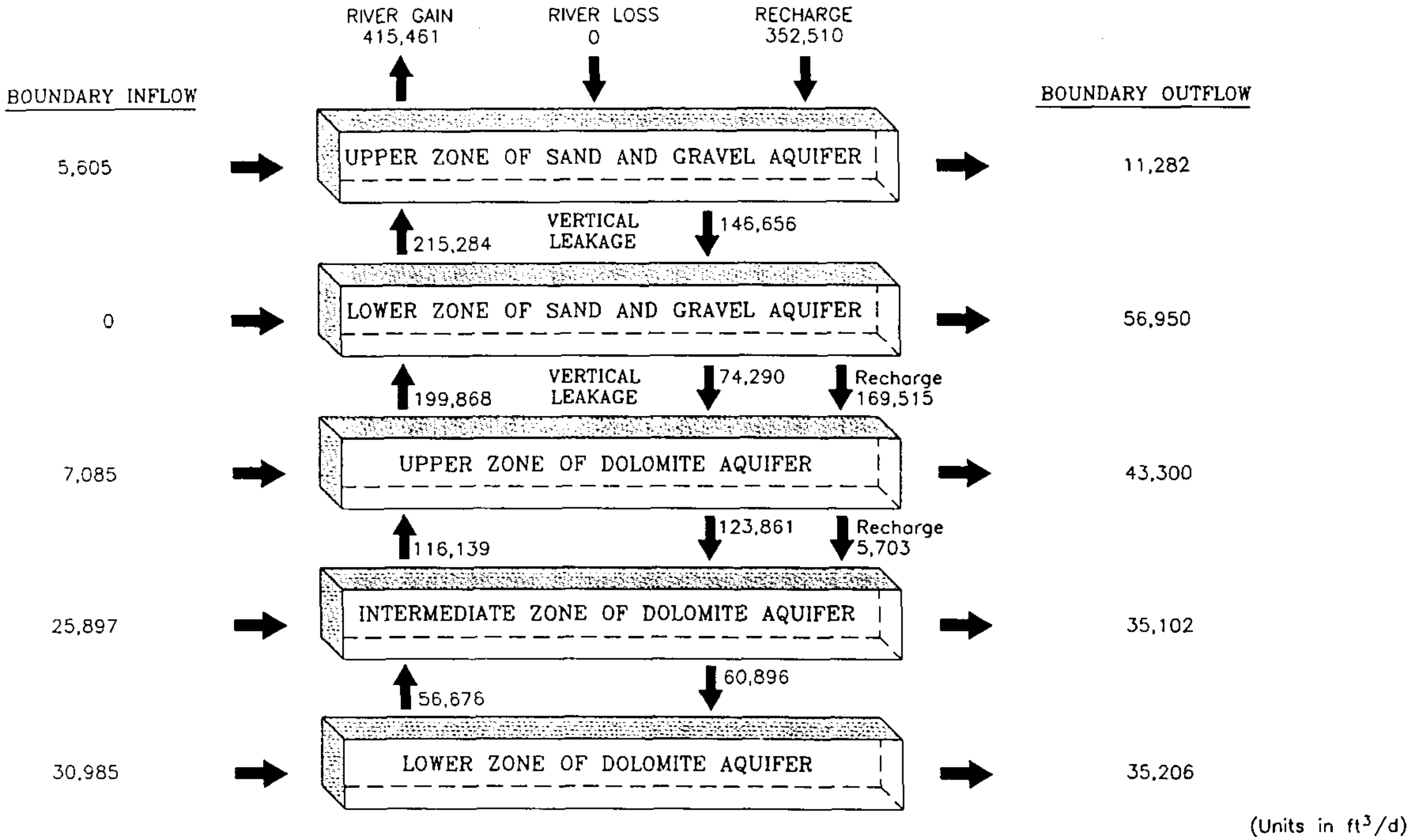
# 5 GROUNDWATER FLOW MODEL ANALYSIS

Based on the calibrated three-dimensional model developed for the WRL, analyses of the groundwater flow budget were performed for the entire model domain and the directions and rates of groundwater flow at the site. The groundwater flow budget for the model, in addition to showing conservation of mass in the calibrated model, indicates the major groundwater sources and sinks in the model and large-scale exchange of groundwater flow between aquifers over the domain of the model. Particle-tracking analyses, performed to evaluate groundwater flow directions from specific locations at the WRL site, provide a more detailed assessment of groundwater movement in the unconsolidated and upper bedrock aquifer system.

## 5.1 MODEL WATER BALANCE

A requirement of groundwater flow simulations with models such as MODFLOW is the conservation of flow over the entire model domain. In other words, for a steady-state simulation, the sum of all sources of groundwater (flow entering the model domain) should balance the total of all groundwater sinks (flow leaving the model domain). In addition to checking the accuracy of a model simulation, an analysis of a model's groundwater flow budget also provides useful insight into the major directions and rates of groundwater flow within the domain of a model.

An analysis of the major groundwater sources and sinks within the WRL groundwater flow model has the components shown in Figure 5-1. This figure summarizes the principal pathways for water entering and leaving the model domain for each layer of the model. On the figure, boundary inflow refers to groundwater entering the model domain through constant head boundary conditions specified in the model. Specifically, boundary inflow through constant head boundaries occurs along the east edge of the model domain, which is upgradient of the WRL site. Conversely, boundary outflow denotes groundwater leaving the model through constant head boundaries. In the WRL model, boundary outflow occurs at the




TITLE: CALIBRATED MODEL WATER BUDGET

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

| | | |
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| CHECKED: | D.B. | FIGURE: 5-1 |
| DRAFTED: | C.S | |
| FILE: | 7735FM16 | |
| DATE: | 6-29-95 | |

constant head boundaries specified in the unconsolidated and bedrock aquifers along the west edge of the model domain. On Figure 5-1, river gains or losses refer to flow entering or leaving surface water bodies represented in the model by river boundary conditions.

The major source of groundwater for the WRL model is precipitation recharge, which recharges both the unconsolidated and bedrock aquifers. Most of the model boundary inflow occurs through the upgradient boundary in the dolomite aquifer. The model shows that a large amount of groundwater discharges to Kilbuck Creek in the model domain. Figure 5-1 also shows the significant amount of vertical flow within the model domain.

## 5.2 PARTICLE TRACKING

Particle-tracking techniques are useful tools for evaluating groundwater flow directions and constituent migration pathways. Particle tracking is a simple form of contaminant transport analysis which neglects the effects of dispersion, retardation, and chemical reactions. Using an initial starting point, particle tracking simulates the movement of a particle through a groundwater velocity field over time. Particle tracking also acts as a check on model calibration by allowing comparison of simulated and observed migration pathways and travel times.

The U.S. Geological Survey particle-tracking code MODPATH (Pollock, 1989) was used to perform particle tracking in this modeling study. Using the calibrated steady-state groundwater flow rates simulated with MODFLOW, MODPATH computes groundwater velocities in the three principal coordinate directions throughout the model domain. To compute these velocities, MODPATH requires site-specific values of effective porosity for each layer of the model. Based on lithologies encountered at the WRL site, effective porosity was estimated based on both laboratory testing and literature values (de Marsily, 1986). The sand and gravel aquifer had an estimated effective porosity of 0.30 based on laboratory testing results. For the dolomite aquifer, the effective porosity was estimated to be 0.10 based on lithology (de Marsily, 1986).

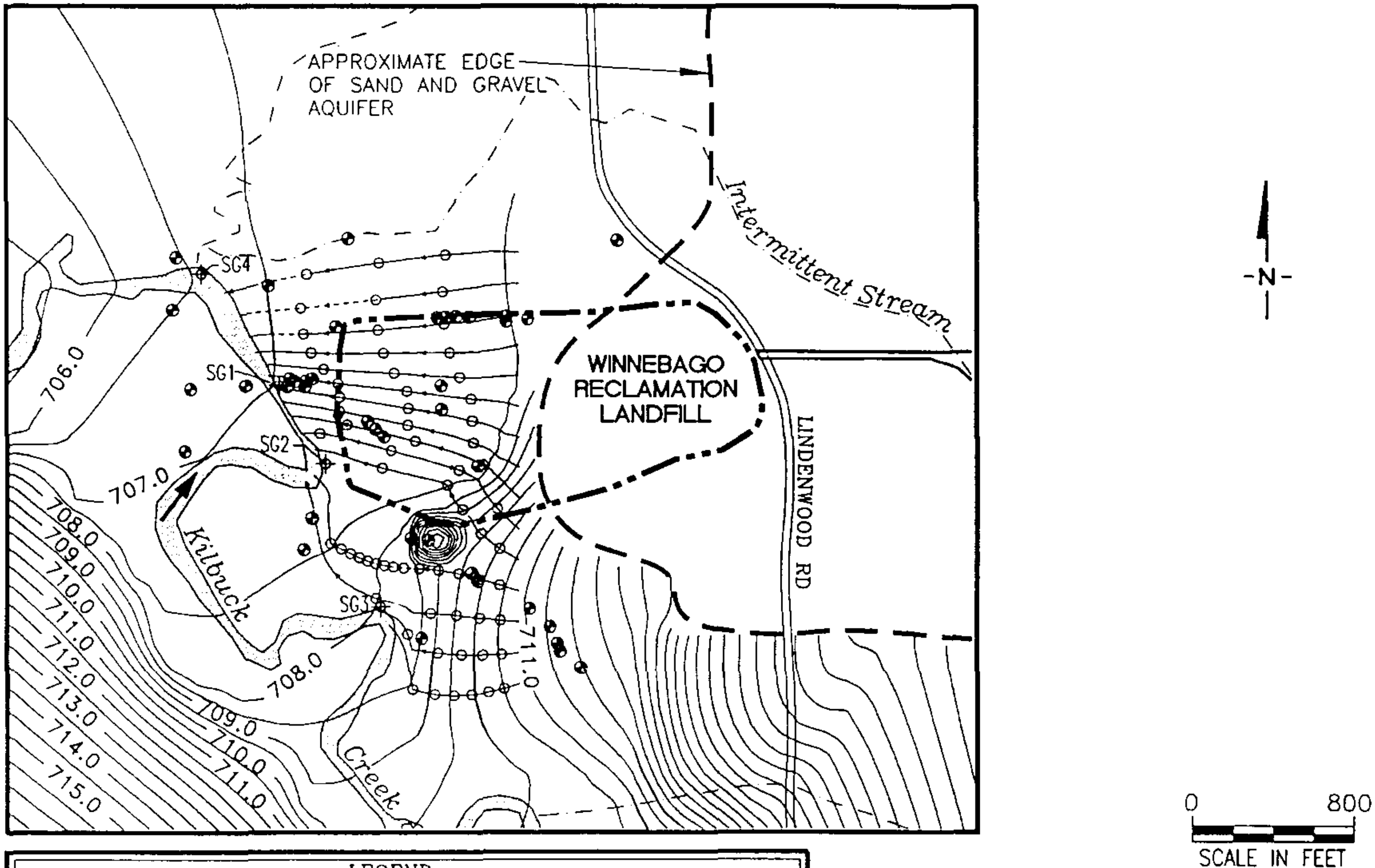
Figure 5-2 shows local particle-tracking results for the upper zone of the sand and gravel aquifer. In this simulation, particles was initially placed in the middle of model layer 1. As expected, these particles discharge to Kilbuck Creek. The estimated travel time from below the central point of the landfill to Kilbuck Creek is 1.5 to 2.0 years.

Particle-tracking results for the lower zone of the sand and gravel aquifer are shown in Figure 5-3. The initial location for particles in this aquifer was the west edge of the landfill and in center of model layer 2. This figure shows that most of the particles flow back up to model layer 1 and discharge to Kilbuck Creek. However, the particle on the central west edge of the landfill flowed beneath Kilbuck Creek and back upward to discharge at a lower reach of Kilbuck Creek. This flow path is consistent with the interpretation that impacted groundwater flows beneath Kilbuck Creek. The upward flow path on the west side of Kilbuck Creek also explains why impacted groundwater is only present in the shallow zone at monitoring well G34S, and not at G34D.

Figure 5-4 shows the particle traces for particles initially placed where the landfill directly overlies saturated bedrock. It is apparent that groundwater particles quickly flow back up into the higher permeability sand and gravel aquifer to the west where it is saturated. This migration pathway explains why no leachate constituents have been detected in downgradient bedrock wells. It therefore follows that any impacted groundwater in bedrock below the landfill will be effectively treated by the downgradient remedial system in the sand and gravel aquifer. The expected travel time to the remedial system for these particles is approximately 2.5 to 3.0 years.

Figure 5-5 shows the forward particle traces from particles initially placed at the locations of the upgradient background monitoring wells G109, G109A, G113, G113A, and G120B. These upgradient background wells are all screened in bedrock because the sand and gravel deposits are not saturated east of the WRL. It is apparent, however, that groundwater particles at these upgradient well locations will flow upward into the sand and gravel aquifer and continue to the west-northwest at the WRL.

It should also be noted that impacted chlorinated compounds, which have migrated from the Acme Solvent Superfund Site, have been historically detected in these wells. Particle tracking shows that this impacted groundwater flows across the southeast corner and continues below the WRL site. This model simulation shows that chlorinated compounds




LEGEND

-720.0- Water-Level Elevation (ft, msl)

Particle Trace in Upper Zone of Sand and Gravel Aquifer (Model Layer 1)

Particle Trace in Lower Zone of Sand and Gravel Aquifer (Model Layer 2)

Particle Location Every 0.5 Years

Monitor Well Location (Unconsolidated Sediments)

SG3 Stream Gage Location

TITLE: FORWARD PARTICLE TRACKING RESULTS FOR THE CALIBRATED FLOW FIELD IN THE UPPER ZONE OF THE SAND AND GRAVEL AQUIFER (MODEL LAYER 1).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc. GROUNDWATER SPECIALISTS

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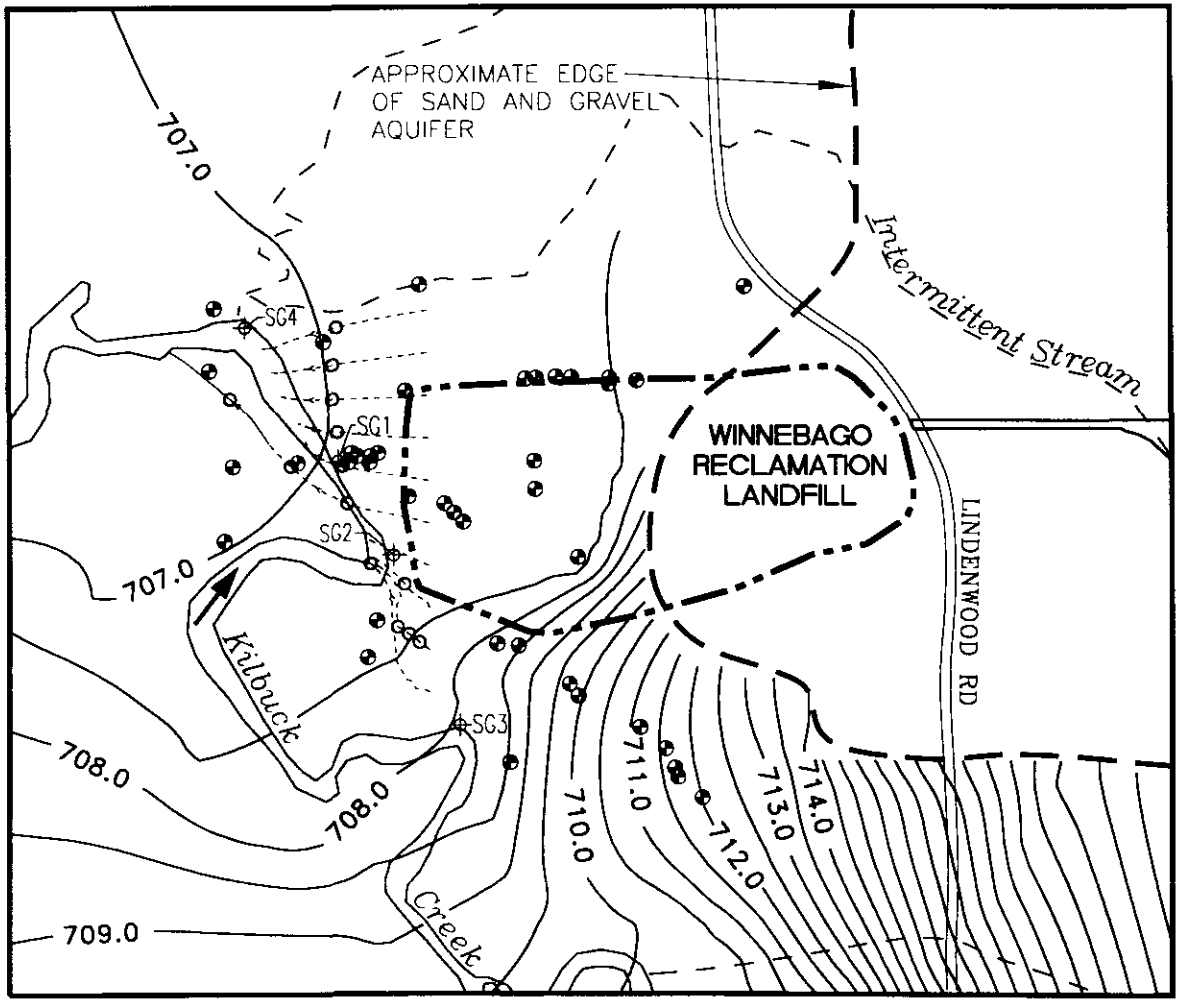
| FILE: | 7735FM11 |
| DATE: | 6-29-95 |

FIGURE: 5-2




-N-

0 800'
SCALE IN FEET

LEGEND

| | |
|---|---|
| -720.0- | Water-Level Elevation (ft, msl) |
| ← | Particle Trace in Upper Zone of Sand and Gravel Aquifer (Model Layer 1) |
| ←----- | Particle Trace in Lower Zone of Sand and Gravel Aquifer (Model Layer 2) |
| o | Particle Location Every 0.5 Years |
| ⊕ | Monitor Well Location (Unconsolidated Sediments) |
| ⊕SG3 | Stream Gage Location |

TITLE: FORWARD PARTICLE TRACKING RESULTS FOR THE CALIBRATED FLOW FIELD IN THE LOWER ZONE OF THE SAND AND GRAVEL AQUIFER (MODEL LAYER 2).

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

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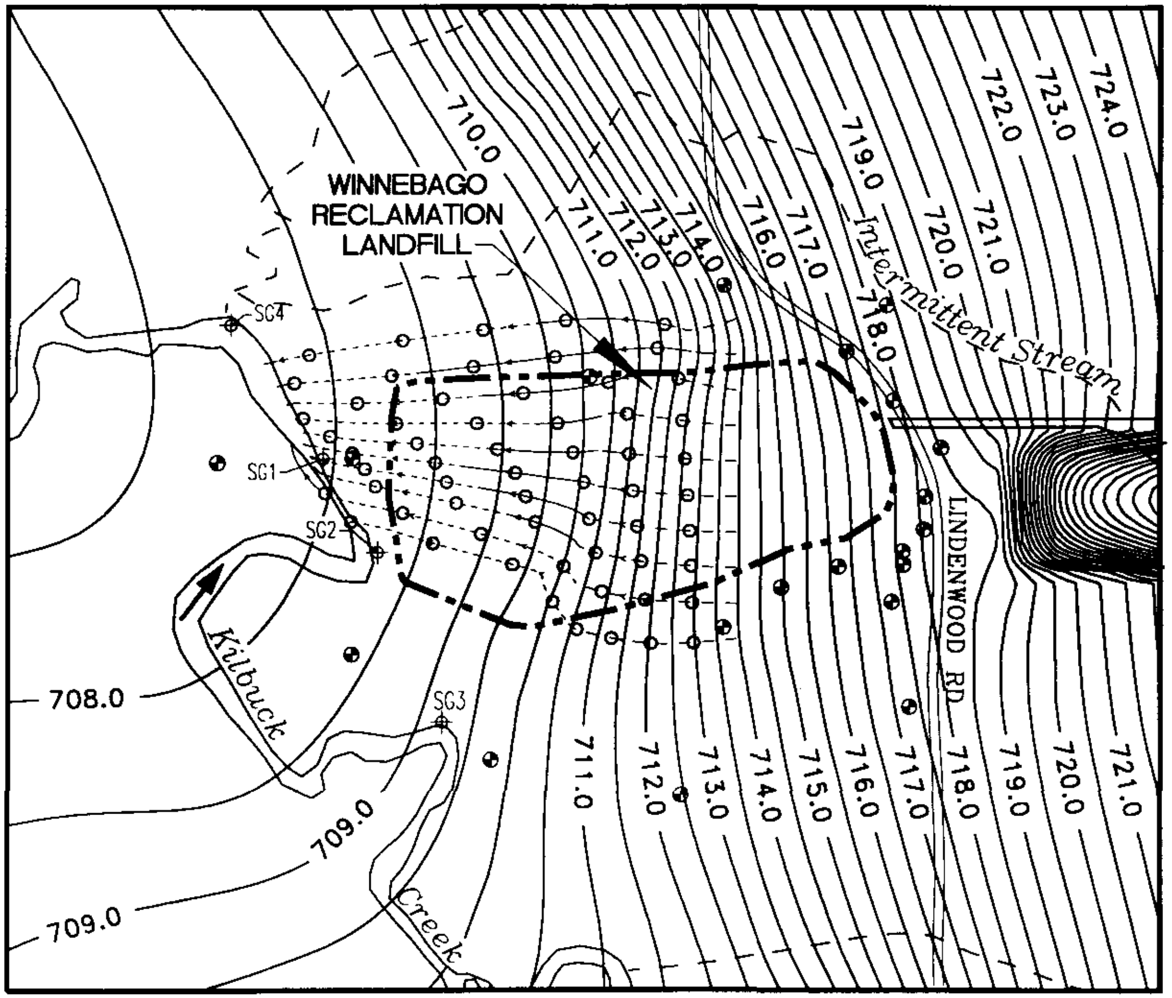
| CHECKED: | D.B. | FIGURE: |
| DRAFTED: | C.S. | 5-3 |
| FILE: | 7735FM12 | |
| DATE: | 6-29-95 | |




-N-

0 800'
SCALE IN FEET

LEGEND

| | | | |
|---|---|---|---|
| -720.0- | Water-Level Elevation (ft, msl) | | |
| | Particle Trace in Upper Zone of Sand and Gravel Aquifer (Model Layer 1) | | Monitor Well Location (Bedrock) |
| | Particle Trace in Lower Zone of Sand and Gravel Aquifer (Model Layer 2) | | |
| | Particle Trace in Upper Zone of Bedrock Aquifer (Model Layer 3) | SG3 | Stream Gage Location |
| o | Particle Location Every 0.5 Years | | |

TITLE: FORWARD PARTICLE TRACKING RESULTS FOR THE UPPER ZONE OF THE DOLOMITE BEDROCK AQUIFER (MODEL LAYER 3) AT THE WRL SITE.

LOCATION: Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

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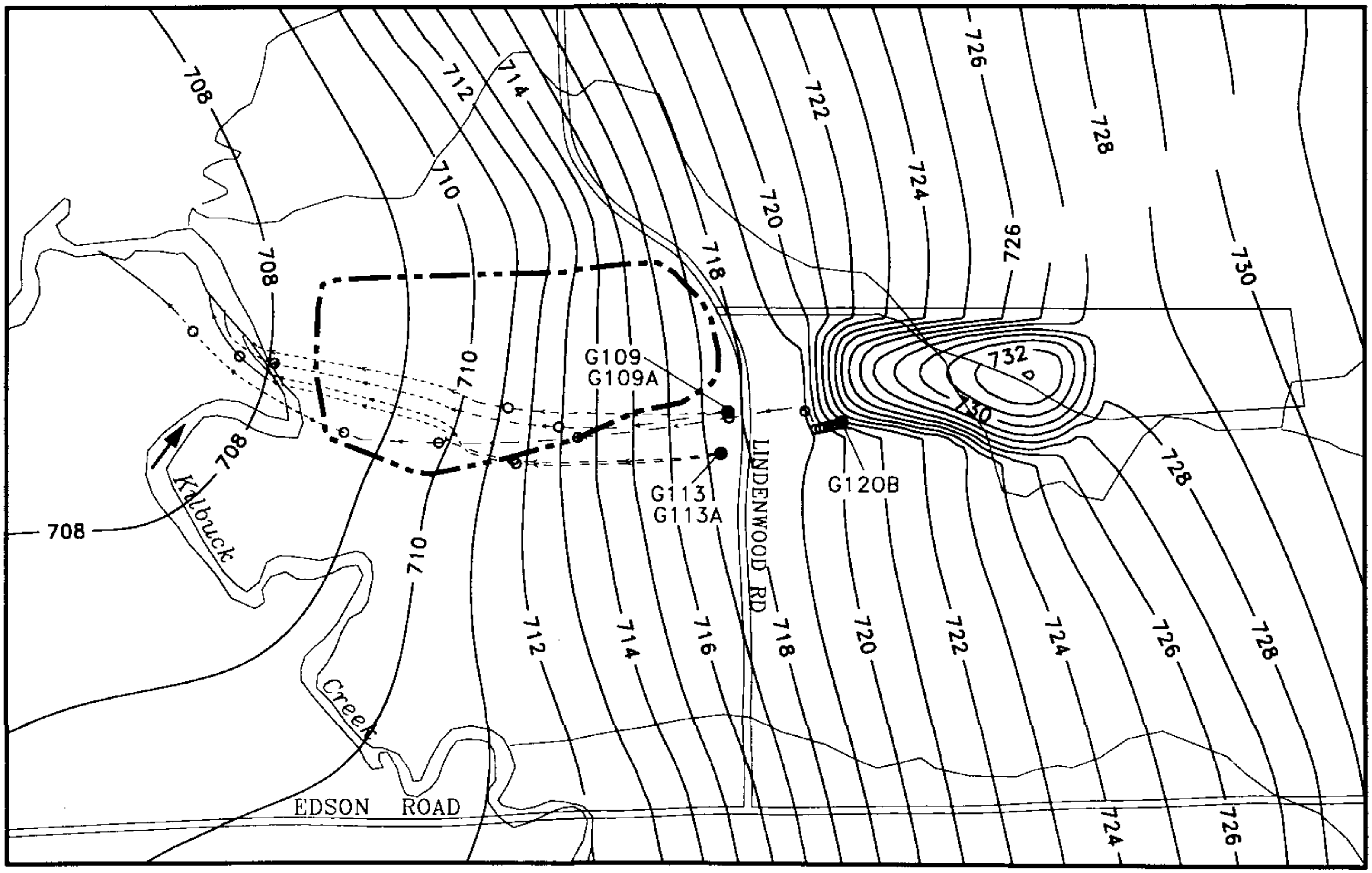
|---|---|---|
| CHECKED: | D.B. | FIGURE: |
| DRAFTED: | C.S. | 5-4 |
| FILE: | 7735FM13 | |
| DATE: | 6-29-95 | |




**LEGEND**

| | |
|---|---|
| –720.0– | Water-Level Elevation (ft, msl) in Model Layer 3 (Upper Bedrock) |
| | Particle Trace in Layer 1 |
| | Particle Trace in Layer 2 |
| | Particle Trace in Layer 3 |
| | Particle Trace in Layer 4 |
| | Particle Trace in Layer 5 |
| o | Particle Location Every 3.0 Years |

-N-

0 900'
SCALE IN FEET

TITLE:
FORWARD PARTICLE TRACES FROM UPGRADIENT BACKGROUND MONITORING WELLS.

LOCATION:
Winnebago Reclamation Services, Rockford, IL.

GeoTrans, inc.
GROUNDWATER SPECIALISTS

| | | |
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located downgradient of the WRL site are probably caused by migration from an upgradient source. This interpretation is supported by the very low levels of chlorinated compounds in the WRL leachate compared to the large amounts of chlorinated compounds released at the upgradient Acme Solvent Superfund Site.

# 6 CONCLUSION

A substantial amount of site-specific data has been collected at and near the WRL site. This data was analyzed in order to develop a detailed conceptual understanding of groundwater flow rates and direction at the WRL site. Careful attention to detail in the development of the three-dimensional groundwater flow model for the WRL resulted in a steady-state calibration of the model that closely reproduces measured groundwater elevations and observed groundwater flow directions. The model-calibrated values of precipitation recharge, horizontal hydraulic conductivity and vertical conductivity generally matched field and laboratory estimates of these parameters. Particle tracking results showed particle traces which are very similar to the observed distribution of elevated constituents in groundwater. Particle tracking also showed that the background wells G109, G109A, G113, G113A, and G120B are along pathways of groundwater flow into the sand and gravel aquifer beneath the WRL. Therefore, these background monitoring wells are appropriately located. In summary, the excellent match with observed data shows that the numerical groundwater flow model will be a useful decision-making tool for future studies at the WRL site.

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FIGURE 1.3
OVERSIZED MAP
"Detailed Site Map"
1 PAGE

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